Adaptation to Climate Change: Land Use and Livestock Management Change in the U.S.

Jianhong H. Mu
Research Assistant
mujh1024@gmail.com

Bruce A. McCarl
Distinguished Professor
mccarl@tamu.edu

Department of Agricultural Economics
Texas A&M University
College Station

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Abstract: This paper examines possible climate adaptations in a U.S. land use and livestock context. By using a statistical model estimated over census and other data, we found that as temperature and precipitation increases producers respond by reducing crop land and increasing pasture land. Our projections indicate that more cropping land would shift to pasture/grazing land under climate change. In addition, we find that cattle stocking rates decrease as summer Temperature and Humidity Index (THI) increases and they are declining under climate change.

Keywords: Climate Change, Stocking Rates, Land Use, Livestock Management

1 Introduction

Climate change impacts land use and livestock management altering crop, forage and livestock growth and yield plus water supply. However, climate change has been projected to cause higher temperatures along with altered precipitation and water supply (IPCC 2007a). It appears that a substantial degree of climate change is inevitable and thus adaptation strategies are necessary (Rose and McCarl, 2008). Agriculture is a highly vulnerable sector to such changes and this raises a need for producers to adapt operations so as to improve performance and profits.

Producers can adapt to climate change by altering management while maintaining or by changing animal species or crop mix among other possibilities (Hoffmann 2010). For example, adaptation might involve substituting livestock for cropping in marginal mixed crop-livestock systems as they become ecologically and socially more marginal (Jones and Thornton 2009) or shifting livestock species along with other possibilities (Herrero et al. 2008). However, studies have not broadly quantified the degree to which such adaptations have occurred in the U.S. and this paper reports on research that attempts to do so.

Specifically, this paper examines the degree to which climate adaptations occur based on observed U.S. land use, climate and livestock data. Namely, we econometrically examine how climatic factors spatially and temporally impact land allocation decisions between crop and livestock along with livestock stocking rates. In turn, based on our estimated results, we project the directions and magnitudes of likely adaptation under selected IPCC 2007 climate change scenarios.

2 Literature Review

A number of studies have been done on livestock adaptation to climate in the context of Africa and South America (Seo and Mendelsohn 2008a; Seo and Mendelsohn 2008b; Seo et al. 2009; Seo et al. 2010). For example, Seo et al. (2010) find that the probability of a farm having livestock increases with warming but decreases when it becomes too wet. In terms of crop livestock shifts, Seo et al. (2009) find that in Africa a hot and dry climate causes a greater incidence of livestock as opposed to crop production in high elevation areas. However, as the climate becomes wetter, livestock ownership falls dramatically in all areas (Seo and Mendelsohn 2008a; Seo and Mendelsohn 2008b).

In the context of the U.S., however, aggregate analyses of direct impacts of climate change on livestock production are rare (Mader et al. 2009). Adams et al. (1999) predict that livestock in the U.S. would be only mildly affected by warming because most livestock receive both protection against the environment and supplemental feed. Hahn et al. (2005) find that changes in climate would directly lead to reductions in summer season milk production and conception rates in dairy cows; Amundson et al. (2006) find that minimum temperature had the greatest influence on the percent of cows getting pregnant, and Nienaber and Hahn (2007) find that normal animal behavioral, immunological, and physiological functions are all potentially impaired as a result of thermal challenges.

Earlier studies of how climate may impact livestock production illustrate the potential for more significant consequences when variability in weather patterns and extreme events increase (Hatfield et al. 2008). Frank et al. (2001) find swine and beef production were affected most in the south-central and southeastern U.S., and dairy production was affected the most in the U.S Midwest and northeast regions. CCSP (2008) presents evidence that increased temperature in warm regions would result in reduced feed intake and affect feed efficiency, animal gain, milk production and reproduction, disease susceptibility, and death. Mader et al. (2009) find that an increase in air temperature will reduce milk production level in the central U.S., while swine producers in northern areas may experience some benefit to climate effects and beef producers would need to feed cattle up to 16% longer.

The literature discussed above largely estimates the climate effects on livestock management in the U.S. without considering the possibility of adaptation in management practices or technological change (Adams et al. 1999; Reilly et al. 2003; Mader et al. 2009). We also cannot find few studies focused on the topic of climatic conditions and livestock stocking rate. To contribute to the literature, we examine how climate change causes farmers to adapt through land allocation and adjust livestock stocking rate and predict the potential changes assuming global warming.

3 Model and Data

3.1 Model

Following the standard assumption of many agro-economic studies, profit π is modeled as a function of climate variables (Schlenker et al. 2006). Assuming the net revenue from agriculture operation j is written as,

$$\pi_j = U_j + \varepsilon_j$$

Where U_j is a function of exogenous characteristics of the district including temperature, precipitation, drought index, extreme hot days and regional dummies; ε_j indicates individual heterogeneity and $j = 1, 2, 3$ represents land use of cropping, livestock operation and other land usage, respectively.

Adapting McFadden's random utility maximization model (McFadden, 1981), farmers will choose land use $j = 1$ over all other land usage if,

$$\begin{aligned} P(j = 1) &= P(\pi_1 = max(\pi_1, \pi_2, \pi_3)) \\ &= P(\pi_1 > \pi_2, \pi_1 > \pi_3) \end{aligned}$$

The probability for the i^{th} district to employ land use $j = 1$ is calculated by integrating the appropriate indicator function as follows:

$$P_{i1} = \int_{\varepsilon} \Phi(\varepsilon_{i2} - \varepsilon_{i1} < U_{i1} - U_{i2}) \cdot \Phi(\varepsilon_{i3} - \varepsilon_{i1} < U_{i1} - U_{i3}) \, f(\varepsilon_{i1}) \, \mathrm{d}\varepsilon_{i1}$$

where Φ is the indicator function and f is the probability density function of the error term.

If we assume that a) the density function f follows an identical and independent Type I Extreme Value distribution ; and b) the observable component U_j can be written as a quadratic function of temperature and precipitation [1] plus a linear form of other independent variables, then the probability of choosing land use j can be derived as,

$$P_{ij} = \frac{e^{U_{ij}\beta_j}}{\sum_{k=1}^{3} e^{U_{ik}\beta_k}} \quad \forall j = 1, 2, 3$$

Based on this equation, we construct a log-likelihood function and parameters can be estimated using a Maximum Likelihood Method. These estimates are consistent and asymptotically normal (Papke and Wooldridge 1996). In particular, we employ a Fractional Multinomial Logit Model as developed and extended by Sivakumar and Bhat

[1] It is reasonable since inputs like climate variables have positive marginal effects that diminish and eventually turn negative.

(2002), Mullahy and Robert (2010) ,Ye, et al. (2005)), and Mullahy (2010 proposes an extension of the fractional regression methodology. For all analyses, we assume the Independence of Irrelevant Alternatives (IIA) hypothesis holds and require that $\sum_{j=1}^{3} P_{ij} = 1$.

The impacts of climate on the district choice of land use can be measured by examining how the selection probabilities for land use are altered by climate and the profitability implications thereof (Seo et al. 2010). Specifically, if land use in cropping is less profitable than livestock operation under a hot climate, farmers will prefer raising livestock to cropping, which reflects itself in a lower choice probability for cropping and a higher one for livestock operation.

The overall profitability of the livestock production system is also impacted by stocking rate through its major impact on animal performance. According to Redfearn and Bidwell, Figure 2 indicates that maximum individual animal performance occurs at light stocking rates because there is little competition for the best forage plants in the pasture. As stocking rate is increased, the level of animal performance is reduced due to increased competition. Figure 2 also indicates that as stocking rate increases, the amount of weight gain produced per acre is increased up to a threshold and then declines. For the analyses of cattle stocking rate, we compare results from OLS regression and Quantile regression.

3.2 Data

Data needed for this study involve land use data, livestock density and climate variables. We decided to use data from the census years of 2007, 2002, 1997, 1992 and 1987 as we think longer period between observations in needed to allow adaptive land use adjustments plus have the cross section to observe adaptation land use patterns across regions characterized by different climates. All are developed at the crop reporting district level. Major data types and sources are:

- Land use data were drawn from the Agriculture Census including total acres of farm land, crop land and pasture land, market values of crop and sold livestock products (both in $1000).
- Crop reporting district-level inventory numbers of beef cows, milk cows, beef cow replacement, milk cow replacement and calves were drawn from the USDA National Agriculture Statistics Service.
- Climate data for temperature and precipitation were obtained from the NOAA Satellite and Information Service, National Climatic Data Center. We use seasonal mean temperature and precipitation for 3 years preceding each census year2.

Given the IPCC (2007a) evidence and projections relative to climate variability, we assembled data reflective of climate variability specifically on drought, extreme heat waves and precipitation intensity.

- For data describing the incidence of drought, we use the Palmer drought index drawn from the NOAA's National Climatic Data Center (NCDC). The Palmer drought index is a measurement of dryness based on recent precipitation and temperature. A negative Palmer index means drought with values below -4 reflecting extreme drought and those above $+4$ indicating extreme wetness.
- For heat waves, we counted the number of days during a year that the maximum temperature was higher than 32°C (~90 F).

[2] For example, when the dependent variable in our model is from 1987, we use the seasonal averaged climate over 1985-1987, and similarly with the other four census.

- For precipitation intensity, we constructed an index of precipitation intensity following that in IPCC (2007a), adding up the percent of annual total precipitation due to events exceeding the 1961-1990 95th percentiles[3].

For the latter two indicators, we were only able to construct state-level information which was insufficient for a panel analysis but enough for a pooled estimation.

To capture differential effects at different latitudes and regions, we added dummies for sub-regional effects using USDA regions. They include,

- Region 1: Corn Belt (CB) which includes states of Illinois, Indiana, Iowa, Missouri and Ohio;
- Region 2: Great Plains (GP) which includes states of Kansas, Nebraska, North Dakota and South Dakota;
- Region 3: Lake States (LS) which includes states of Michigan, Minnesota and Wisconsin;
- Region 4: Northeast (NE) which includes states of Maryland, New Jersey, New York, Pennsylvania, Vermont and West Virginia;
- Region 5: Rocky Mountains (RM) which includes states of Arizona, Colorado, Idaho, Montana, Nevada, New Mexico, Utah and Wyoming;
- Region 6: Pacific Southwest (PSW) which includes California. We use it as the base level since it has the fewest sample.

[3] The equation for calculation the precipitation index is,

$$pre\,\mathrm{int} = \frac{\text{(total precipitation that exceed 95 percentile)*100}}{\text{total yearly precipitation}}$$

- Region 7: Pacific Northwest east side (PNWE) which includes sates of Oregon and Washington;
- Region 8: South central (SC) which includes states of Kentucky, Tennessee, Alabama, Arkansas, Louisiana, Mississippi;
- Region 9: Southeast (SE) which includes states of Virginia, North Carolina, South Carolina, Florida and Georgia;
- Region 10: South west (SW) which includes states of Oklahoma and Texas.

Additionally, we needed data on the livestock stocking rate and needed to construct it from the other data we collected. Mathematically, stocking rate is defined as the number of animals on a given amount of land over a certain period of time (Redfearn and Bidwell). We also needed to account for herd composition. To do this developed a district level number of equivalent animals based on the Animal Unit Month (AUM) requirements and inventory numbers of beef cows and milk cows, beef cow replacements, milk cow replacements, and calves in each district.

Following Redfearn and Bidwell and Pratt and Rasmussen (2001)[4], we assume that AUM requirements for milk cows, replacements of beef cows and cows, and calves are 1.5, 0.7, 0.8, and 0.6, respectively. Hence, the stocking rate (SR) of cattle in each district is calculated as follows,

$$SR = \frac{\sum_i AUM_i * Inventoty_i}{Pastureland}$$

where $i =$ beef cows, milk cows, replacement of beef cows, replacement of milk cows, and calves, respectively and $Pastureland$ is the total acre of pasture land in each district.

[4] Pratt and Rasmussen(2001) give full information of defining and calculating the stocking rate for each animal

However, there are missing observations as the data do not report inventory of cattle or there is no cattle inventory in some districts, so we use the log term of cattle stocking rate as follows,

$$\log(SR) = \log(\frac{\sum_i AUM_i * Inventoty_i}{Pastureland} + 1)$$

According to agronomic studies, plant growth is partly nonlinear in weather (Black and Thompson 1978; Adams et al. 1999; Schlenker and Roberts 2009). Specifically, Schlenker and Roberts (2006) find that that plant growth is linear in temperature only within a certain range, between specific lower and upper thresholds, beyond which higher temperature becomes harmful. So in this paper, we impose the squared terms of temperature and precipitation as we discussed in previous part.

For animal stocking rate analysis, we introduce the temperature-humidity index (THI) index to determine the effect of summer conditions on animal comfort, combining temperature and humidity and measured by respiration rate. For example, if $74 \le THI < 79$, it indicates that the respiration rate of livestock reach the range between 90 and 110, which is the threshold for alerting livestock's safety; if $THI \ge 79$, the respiration rate will reach the range between 110 to 130 which is dangerous for farm animals. Therefore, the THI have been used to provide guides for environmental management and assessment of risk for losses through linkages with responses related to animal performance (Mader et al. 2006; Bohmanova et al. 2007). Since it is difficult for us to get the THI directly, it could be computed according to previous literatures using the following formula,

$$THI = 0.8 * Ta + (RH/100) * (Ta - 14.3) + 46.4$$

and,

$$RH = (6.1121) * e\wedge(18.678 - Ta / 234.5)(Ta / (257.14 + Ta))$$

where Ta = temperature, °C and RH is the relative humidity.

We have 1034 observations in total and the sum of crop land use and pasture land use takes amounts to over 90% of total land in farms during 1987-2007. Descriptions and Statistical characteristics of variables are listed in Table 1 for each census year as well for the pooled sample. Figure 1 shows that both the percentage of crop land use and pasture land use exhibits a decreasing trend from 1987 to 2007.

4 Estimation Results

Now we turn to the estimation results and robustness test. Due to difference in cropping patterns and livestock management across sub-regions, we estimate models with and without sub-regional dummies[5]. By testing model specification, we report regression results coming from models that passed the log-likelihood ratio test. In other words, models with sub-regional dummies are presented and interpreted.

4.1 Land use allocation and climate

Table 2 reports marginal effects of continuous explanatory variables from the estimated Fractional Multinomial Logit (FMNL) model of land use choices with the marginal effects of regional dummies omitted. Since we have five agriculture census years and each has a five-year gap, we report regression results for each census year and for the pooled sample.

Although the significance levels vary between the equations estimated over the different data sets, we find consistent signs for important climate variables, such as

[5] Regression results of model without sub-regional dummies are reported in appendix to save pages. Similarly, we put results of other land use in appendix as well since it is out of the purpose of this paper.

precipitation and temperature across the various data sets, which suggests that our model specification is robust for different samples.

Cropping and livestock operation compete for land use as signs of climate variables in their respective regression equations are opposite. Results indicate that crop land increases when precipitation increases but decreases when there is excessive spring and winter precipitation. The response to precipitation reaches its peak at 15.2 inches for the pooled group which is about half of the 31 inches estimated on a smaller regional basis by Schlenker et al. (2006)[6]. In contrast, the percent of pasture land shrinks as spring and winter precipitation increases; however, it increases when rainfall exceeds 16.5 inches. The mean precipitation is about 9.32 inches in spring and 8.69 inches in winter, which is lower than the peak point, so the change of land use between crop and pasture would be very small due to precipitation changes.

Figure 3 shows the predicted probability of using land for livestock as annual mean precipitation varies. It could be seen that the relationship between precipitation and land use allocation is consistent with our regression results that effects of precipitation has inverted-U shape for crop land use and U shape for livestock operation.

Effects of temperature on choices of land use vary depending on season with the signs of the coefficients following our expectations. On one hand, cropping growing in spring needs temperature rises, however, when temperature increases beyond a threshold of 18^{o}C, it will become harmful and not suitable for crop production. On the other hand, temperature in summer is harmful for crop growing since the mean temperature in

[6] Schlenker et al. (2006) stated that 31 inches is close to the water requirement of many crops although their results were adjusted for the length of the growing season. However, they consider the case for east of the 100th meridian rather than the whole U.S.

summer is already 30 ^{o}C. Under hot temperature, livestock is more hot tolerant compared to crop, which causes farmers to switch land to livestock production.

In general, effects of annual mean temperature and probability of land use allocation are nonlinear as shown in Figure 4. If temperature rises in the future, farmers could adapt to climate change by early planting in spring or switching crop land to pasture land if it is too hot in summer.

The probabilities of land use depend on region. Figure 5 shows the predicted probability of land use allocation between crop and pasture for various regions. Region 1 – the Corn Belt - has the highest probability of crop land use. In contrast, region 5 – Rocky Mountains- and 10 -South West- have the highest probabilities of pasture land use. These land allocation patterns are consistent with current land use.

The Palmer drought index is also important for land allocation. We find that increased drought incidence in summer tends to move land into livestock uses and reduce crop land. Additionally, an increase in the number of hot days in summer also causes a shift into livestock.

We examine results for each census group so as to provide an alternative robust test for model specification (Schlenker et al. 2006). Test results show that there is little change of estimated coefficients. However, the p-values for pairwise Chow-test reveal that we cannot reject the null hypothesis at the 5% confidence level, which means there is no difference in any of the five tests. In other words, our estimations for different sample groups are consistent and our model specification is robust.

4.2 Cattle stocking rate and climate

Forage production and stocking rate records are critical in making timely management decisions (Redfearn and Bidwell). So in this part, we will focus on the analysis of cattle stocking rates. Table 3 shows results from OLS and Quantile regressions. For most independent variables, the coefficients from the two models exhibit the same signs. However, we interpret results from the OLS model since it has a relative higher R-square.

Moisture is generally the most limiting factor relative to forage production, which would in turn, impact stocking rates. Results from Table 3 shows that coefficients of precipitation are significant and show an increase in moisture in summer and winter initially decreases the amount of land needed per animal but peaks at 15 inches in summer and 26 inches in winter in where open the amount of land increases. These numbers change across regions since vegetation on a particular site varies in composition and production largely because of changes in precipitation (Redfearn and Bidwell). Higher precipitation intensity increases the need for land and reduces cattle stocking rates.

Though only spring temperature is significant in the OLS model, we use the temperature humidity index (THI) in the analysis since it is a commonly used index in livestock production studies (Mader et al. 2006; Bohmanova et al. 2007). In particular, a higher THI index in the summer is harmful for livestock perform by reducing their feed intake, energy saving and weights, which induces a lower number of animals per acre, and a heavier stocking rate in the spring or winter. Results from our analysis are consistent with previous studies (Hahn et al. 2005; Nienaber and Hahn 2007), that have shown climatic factors, such as temperature and humidity, affected to livestock production.

Based on the OLS estimation, we simulate 500 times to get parameters of summer precipitation, its square term and the THI index and show their effects on cattle stocking rates in Figure 6 and 7[7]. Particularly, summer precipitation in Figure 6 shows a positive impact on cattle stocking rates with declining marginal values; in contrast, its square term shows a negative effect with increasing marginal values. Their combination presents an inverted-U shape correlation as the results in Table 3. Figure 7 plots effects with confidence level in region 1, 3 and 8 plus the reference level. It can be seen that as summer THI index increases, cattle stocking rates would decline, which suggests a negative and significant relationship between summer THI index and cattle stocking rates.

Since the ability to calculate stocking rates and make timely management decisions is vital to maximizing net returns from the livestock operation, cattle stocking rate is also influenced by the market value of sold livestock products. In other words, they have a positive and significant correlation. If livestock is more profitable, stocking rates will increase until reaching the frontier in Figure 2, after the maximized point, the net return from livestock production will decline as stocking rates increase.

[7] According to our regression results from two models, only region 1, 3 and 8 are statistically significant, we plot effects of summer THI index on cattle stocking rate only in these regions plus in the base region.

5 Projection of land use allocation and stocking rate under climate change

In previous sections, we have shown that regression models used in this paper not only follows the economic theory, but also fits the dataset so as providing credible and robust results. Before going to the conclusion part, we take one more step for considering whether famers' expectation of climate change would impact their behaviors on land use allocation and livestock management.

We use the estimated coefficients from our regressions and the climate model used in IPCC 4th Assessment Report (2007) to evaluate the impacts of climate change. We choose the third version of Hadley Center Coupled Model (HadCM3), which has a stable climate in the global mean (Collins et al. 2001) and also is a mid-sensitivity model (Schlenker et al. 2006).Basically, we use the projected changes in temperature and precipitation for three standard emission scenarios defined in IPCC Special Report on Emission Report (SRES) (Nakicenovic et al. 2000). The choice of climate scenarios is important because it can determine the outcome of a climate impact assessment, so we choose three scenarios range from the lower-emission SRES scenario B1 to a higher-emission scenario A2, and also include the medium-emission scenario A1B given their assumptions on greenhouse gas concentrations (IPCC 2007a).

We use historical data of 1961-1990 mean monthly values as the base for calculating the average projected temperature and precipitation for the years 2010-2039, 2040-2069 and 2070-2099. We emphasize how climate influence the changes of stocking rate, land for pasture or crop in current term, in near the medium term and in a long term. Table 4 shows the annual mean temperature changes under different emission scenarios.

Projected changes in temperature falls within the range of 1-4.2^{o}C (i.e. 34-39 Fahrenheit), which is close to the “likely” range for climate sensitivity in IPCC 4th Assessment Report of 2–4.5°C. More specific, Table 4 also gives the seasonal changes of maximum, minimum and mean temperature and precipitation, and we will use the mean temperature for calculating their marginal effects on stocking rate and land use for pasture and crop.

To get the changes of land use allocation under climate change, we hold other independent variables at mean and use the changes of temperature and precipitation from climate model across three time periods. Table 5 presents marginal effects of changes in temperature and precipitation on the probability of land use allocation and livestock stocking rate under different emission scenarios.

To get changes of cattle stocking rate under climate change, we use the same way to get changes of temperature and precipitation. In addition, we calculate the changes of the THI index under climate change according to the formula in data part and get the percentage changes of cattle stocking rate across time and emission scenarios.

Under current condition, the probability of land use for crop, pasture and other usage is 0.6, 0.29 and 0.11, respectively. By the end of 21st century, the likelihood of crop land use declines with the probability of crop land falling 0.3 under scenario B1 and 0.44 under A2 emission scenarios. By contrast, the probability of pasture use increases 0.28-0.41 under B1 scenario and 0.35-0.53 under A2 scenario.

Currently, cattle stocking rate is about 0.25 animal/ acre. Under climate change, Table 5 also shows cattle stocking rate decreases and the percent change of cattle stocking rate range is about 35%-49% under the lowest emission scenario, and 48%-70% under the highest emission scenario.

Based on our estimation results, we also compute the changes of probability of land use for each region. Figure 8 and 9 shows the results. It can be seen that the probability of land use for livestock is increasing as temperature increases, which in turn, induces a decreasing probability of land use for cropping. The changes in land use vary across regions, for example, Corn Belt region has the largest increase in pasture land.

6 Concluding Comments

In this paper, we have analyzed forms of US livestock production adaptation to climate change econometrically using district-level agricultural census data. Specifically, we first examined how land use between crops and pasture land plus cattle stocking rate are adapted across climatic conditions. After estimation, we find climate change leads to reductions in cattle stocking rates, and land use shifts from crops to pasture.

Results found in this paper are consistent with previous studies (Schlenker et al 2005; Schlenker and Robert 2006), that is, climate is affecting the allocation of land use by reducing crop land and increasing pasture land as temperature and precipitation change. Additionally, cattle stocking rates are also declining under climate change projections.

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Table 1 Statistical Characteristics of Variables

Variable	Interpretation	Mean	Mean	Mean	Mean	Mean	Mean	Min	Max
crop	Percent of crop land	0.58	0.58	0.58	0.61	0.56	0.58	0.00	0.96
		0.25	0.26	0.24	0.22	0.23	0.24		
pasture	Percent of pasture land	0.33	0.33	0.31	0.27	0.30	0.31	0.01	0.98
		0.25	0.26	0.25	0.22	0.23	0.24		
other	Percent of other land usage	0.09	0.09	0.10	0.13	0.14	0.11	0.00	0.53
		0.08	0.07	0.08	0.10	0.11	0.09		
sppcp	Spring precipitation	8.04	8.19	10.40	11.41	8.71	9.32	0.12	37.57
		3.08	3.03	5.83	5.19	3.54	4.46		
sppcp2	Squared spring precipitation	74.12	76.24	142.09	156.92	88.36	106.78	0.01	1411.51
		53.59	50.07	160.49	126.88	70.19	107.11		
smpcp	Summer precipitation	10.53	12.24	10.94	10.48	10.72	10.97	0.04	33.47
		4.47	5.59	4.23	4.84	4.84	4.84		
smpcp2	Squared summer precipitation	130.77	181.03	137.40	133.17	138.26	143.62	0.00	1120.24
		102.26	145.16	96.06	127.34	109.97	117.86		
wtpcp	Winter precipitation	8.79	7.87	9.00	8.60	9.05	8.69	0.27	44.99
		6.11	5.29	6.11	6.23	5.05	5.76		
wtpcp2	Squared summer precipitation	114.51	89.73	118.13	112.62	107.35	108.63	0.07	2024.10
		142.38	126.83	162.45	199.60	145.83	156.70		
sptmp	Spring temperature	54.67	52.63	51.32	51.98	54.48	53.07	32.07	73.80
		6.74	8.07	9.63	9.63	7.78	8.51		
sptmp2	Squared spring temperature	3034.02	2834.71	2725.55	2793.82	3028.07	2889.14	1028.49	5446.44
		753.19	868.46	1014.41	1010.79	850.12	909.93		
smtmp	Summer temperature	73.75	70.29	71.91	74.00	73.95	72.83	57.77	85.80
		5.60	6.28	5.64	5.06	5.39	5.77		
smtmp2	Squared summer temperature	5470.60	4980.33	5202.79	5500.86	5497.98	5337.35	3337.37	7361.64
		823.05	893.74	820.10	739.19	790.94	837.88		
wttmp	Winter temperature	35.51	36.01	34.42	36.11	32.61	34.82	6.53	64.53

		9.71	10.61	11.57	8.97	12.30	10.85		
wttmp2	Squared winter temperature	1354.77	1408.82	1318.05	1384.32	1214.15	1330.17	42.64	4164.12
		737.41	792.26	820.84	666.57	830.45	777.09		
sppmdi	Spring Palmer drought index	-0.17	-0.33	1.68	-0.31	0.02	0.19	-7.35	6.72
		1.80	2.26	1.66	2.28	2.22	2.19		
smpmdi	summer Palmer drought index	-0.54	0.59	1.55	-0.61	-0.61	0.06	-9.47	9.37
		2.07	2.28	1.73	2.25	2.26	2.29		
wtpmdi	Winter Palmer drought index	0.58	0.54	1.68	-0.19	0.50	0.63	-5.48	5.98
		1.43	1.93	1.22	1.63	1.89	1.75		
preint	Precipitation intensity index	0.18	0.19	0.17	0.16	0.15	0.17	0.00	0.70
		0.08	0.16	0.07	0.06	0.08	0.10		
hd32	Number of hot days with	34.54	16.74	24.11	37.18	33.72	29.42	0.00	125.00
	temp>32^{o}C	29.14	24.31	28.52	25.08	26.65	27.83		
lcv	Log term of crop value	11.62	11.85	12.11	12.40	13.34	12.30	7.92	16.12
		1.27	1.27	1.25	1.33	1.10	1.38		
lsv	Log term of livestock value	11.92	11.96	12.08	12.46	13.36	12.39	8.47	16.71
		0.99	0.99	1.06	1.12	0.97	1.17		
lnsr	Log term of stocking rate	0.22	0.22	0.22	0.32	0.29	0.26	0.00	1.90
		0.21	0.21	0.25	0.24	0.24	0.23		
spthi	Spring temperature-humidity index	63.00	62.61	62.58	62.71	62.89	62.76	61.92	68.07
		0.98	0.90	1.06	1.14	0.88	1.00		
smthi	Summer temperature-humidity	68.46	66.57	67.31	68.51	68.46	67.89	62.02	77.39
	index	3.47	3.45	3.40	3.08	3.33	3.43		
wtthi	Winter temperature-humidity index	61.98	61.99	61.98	61.96	61.99	61.98	61.92	64.25
		0.20	0.22	0.23	0.16	0.23	0.21		
Observations		203	192	209	190	240		1034	
Census Year		1987	1992	1997	2002	2007		1987-2007	

Table 2 Marginal Effects from the Factional Multinomial Logit Model

Year	1987		1992		1997		2007		87-07	
variable	crop	pasture	crop	pasture	crop	pasture	crop	pasture	crop	pasture
sppcp	0.0684***	-0.0533***	0.0099	-0.0135	0.0267**	-0.0234**	0.0210	-0.0128	0.0212***	-0.0165***
	(0.0229)	(0.0227)	(0.0279)	(0.0274)	(0.0134)	(0.0138)	(0.0181)	(0.0168)	(0.0077)	(0.0064)
sppcp2	-0.0026***	0.0021**	0.0002	0.0002	-0.0006*	0.0006*	-0.0013**	0.0010*	-0.0007**	0.0005***
	(0.0011)	(0.0011)	(0.0011)	(0.0011)	(0.0004)	(0.0004)	(0.0007)	(0.0006)	(0.0003)	(0.0002)
smpcp	0.0277**	-0.0454***	0.0084	-0.0134	-0.0314*	0.0435**	0.0084	-0.0355**	0.0160**	-0.0287***
	(0.0166)	(0.0168)	(0.0188)	(0.0188)	(0.0201)	(0.0216)	(0.0183)	(0.0176)	(0.0080)	(0.0076)
smpcp2	-0.0005	0.0011**	0.0000	0.0001	0.0012**	-0.0018***	0.0002	0.0008*	-0.0003	0.0008***
	(0.0005)	(0.0005)	(0.0005)	(0.0006)	(0.0007)	(0.0008)	(0.0007)	(0.0006)	(0.0003)	(0.0002)
wtpcp	0.0050	-0.0169*	0.0089	-0.0121	0.0211**	-0.0198*	0.0159*	-0.0305***	0.0076*	-0.0121***
	(0.0107)	(0.0108)	(0.0172)	(0.0172)	(0.0121)	(0.0127)	(0.0121)	(0.0112)	(0.0054)	(0.0049)
wtpcp2	-0.0001	0.0005	-0.0002	0.0003	-0.0004	0.0002	-0.0001**	0.0006**	-0.0001	0.0002**
	(0.0004)	(0.0004)	(0.0006)	(0.0005)	(0.0004)	(0.0004)	(0.0003)	(0.0003)	(0.0002)	(0.0001)
sptmp	0.1072	-0.1351	0.1024*	-0.1149*	0.1171***	-0.0535	0.0457	-0.1356**	0.0390***	-0.0223**
	(0.1207)	(0.1139)	(0.0802)	(0.0802)	(0.0464)	(0.0453)	(0.0714)	(0.0671)	(0.0124)	(0.0123)
sptmp2	-0.0007	0.0011	-0.0012*	0.0014**	-0.0016***	0.0008**	-0.0005	0.0016**	-0.0006***	0.0004***
	(0.0012)	(0.0011)	(0.0008)	(0.0008)	(0.0005)	(0.0005)	(0.0007)	(0.0007)	(0.0001)	(0.0001)
smtmp	-0.1960	0.2998**	-0.0838	0.1772*	-0.2411**	0.1798*	-0.1342	0.4997***	-0.1283***	0.1588***
	(0.1732)	(0.1570)	(0.1240)	(0.1199)	(0.1137)	(0.1177)	(0.1341)	(0.1237)	(0.0473)	(0.0438)
smtmp2	0.0014	-0.0022**	0.0009	-0.0016**	0.0021***	-0.0016**	0.0012	-0.0038***	0.0011***	-0.0013***
	(0.0012)	(0.0011)	(0.0009)	(0.0009)	(0.0008)	(0.0009)	(0.0009)	(0.0009)	(0.0003)	(0.0003)
wttmp	-0.0226	0.0222	-0.0484***	0.0390**	-0.0356***	0.0083	-0.0330***	0.0374***	-0.0110**	0.0068
	(0.0255)	(0.0254)	(0.0200)	(0.0188)	(0.0153)	(0.0149)	(0.0115)	(0.0114)	(0.0056)	(0.0058)
wttmp2	0.0000	0.0000	0.0005**	-0.0005*	0.0006***	-0.0002	0.0003*	-0.0005***	0.0002**	-0.0001
	(0.0004)	(0.0004)	(0.0003)	(0.0003)	(0.0002)	(0.0002)	(0.0002)	(0.0002)	(0.0001)	(0.0001)

sppmdi	-0.0230	0.0123	-0.0344	0.0206	-0.0111	0.0222	0.0814***	-0.0802***	-0.0054	0.0015
	(0.0212)	(0.0215)	(0.0309)	(0.0309)	(0.0220)	(0.0234)	(0.0211)	(0.0225)	(0.0083)	(0.0084)
smpmdi	-0.0249*	0.0165	-0.0328**	0.0345***	-0.0316**	0.0382***	-0.0409***	0.0473***	-0.0212***	0.0258***
	(0.0168)	(0.0177)	(0.0152)	(0.0143)	(0.0143)	(0.0143)	(0.0135)	(0.0137)	(0.0070)	(0.0067)
wtpmdi	0.0390**	-0.0297*	0.0463*	-0.0306	0.0244	-0.0404**	-0.0253*	0.0190	0.0184***	-0.0167***
	(0.0216)	(0.0225)	(0.0319)	(0.0318)	(0.0206)	(0.0191)	(0.0180)	(0.0184)	(0.0071)	(0.0071)
preint	0.6246***	-0.6234***	0.1088	-0.1329	0.2632	-0.1706	-0.3873**	0.3313**	0.1256**	-0.0515
	(0.2419)	(0.2471)	(0.1462)	(0.1329)	(0.2826)	(0.2647)	(0.1796)	(0.1756)	(0.0589)	(0.0599)
hd32	-0.0032**	0.0036***	-0.0042***	0.0036**	-0.0044***	0.0057***	-0.0024**	0.0015	-0.0034***	0.0029***
	(0.0015)	(0.0014)	(0.0017)	(0.0017)	(0.0013)	(0.0013)	(0.0012)	(0.0012)	(0.0007)	(0.0007)

Note: Marginal effects of each independent variable on land use of cropping and livestock operation are reported in this Table. Effects of regional dummy variables are omitted and robust standard errors are in parentheses; Asterisk of ***, ** and * represents significance at 1%, 5% and 10% confidence level, respectively; Regression results of census year 2002 are dropped because of collinearity of two sub-regional dummies.

Table 3 Regression Results for Cattle Stocking Rate

Variable	OLS	Quantile	variable	OLS	Quantile
cb	0.1673**	0.1404***	sptmp	0.0613***	0.0425***
	(0.0710)	(0.0487)		(0.0145)	(0.0133)
gp	0.1014	0.0478	sptmp2	-0.0009***	-0.0006***
	(0.0705)	(0.0535)		(0.0002)	(0.0002)
ls	0.3307***	0.2938***	smtmp	-0.0315	0.0131
	(0.0765)	(0.0503)		(0.0479)	(0.0418)
ne	0.1182	0.0981**	smtmp2	0.0005	0.0000
	(0.0758)	(0.0476)		(0.0004)	(0.0004)
rm	0.0699	0.0523	wttmp	0.0039	0.0010
	(0.0505)	(0.0415)		(0.0053)	(0.0038)
pswe	0.0282	0.0282	wttmp2	0.0001	0.0001
	(0.0401)	(0.0380)		(0.0001)	(0.0001)
sc	0.0917	0.0729	sppmdi	-0.0104	-0.0069
	(0.0553)	(0.0448)		(0.0072)	(0.0057)
se	0.1455***	0.1005**	smpmdi	0.0007	-0.0021
	(0.0541)	(0.0437)		(0.0061)	(0.0042)
sw	0.1410**	0.0391	wtpmdi	0.0066	0.0034
	(0.0672)	(0.0505)		(0.0079)	(0.0055)
sppcp	-0.0017	0.0031	preint	-0.1992***	-0.0900*
	(0.0042)	(0.0040)		(0.0619)	(0.0473)
sppcp2	0.0003	0.0000	hd32	-0.0007**	-0.0009***
	(0.0001)	(0.0001)		(0.0004)	(0.0003)
smpcp	0.0091*	0.0123***	lsv	0.0502***	0.0415***
	(0.0051)	(0.0044)		(0.0084)	(0.0039)
smpcp2	-0.0003*	-0.0003**	spthi	0.1627***	0.0918***
	(0.0002)	(0.0001)		(0.0290)	(0.0204)
wtpcp	0.0210***	0.0126***	smthi	-0.0590**	-0.0157
	(0.0048)	(0.0030)		(0.0258)	(0.0190)
wtpcp2	-0.0004**	-0.0002**	wtthi	-0.0707	-0.0807*
	(0.0002)	(0.0001)		(0.0484)	(0.0444)
constant	-3.6922	-1.8639	R-Square	0.3601	0.2631
	(3.4528)	(3.2979)			

Note: Coefficients are reported in this table. The robust standard error of OLS model and the bootstrap standard error of Quantile are in parentheses; Asterisk of ***, ** and * represents significance at 1%, 5% and 10% confidence level, respectively.

Table 4 Predicted changes in temperature and precipitation under different scenarios from HadCM3 model

	2010-2039				2040-2069				2070-2099			
Variable	Mean	Std. Dev.	Min	Max	Mean	Std. Dev.	Min	Max	Mean	Std. Dev.	Min	Max
HadCM3-B1 emission scenario												
sptmp	1.36	0.60	0.30	2.96	1.84	0.71	0.30	3.62	2.28	0.94	0.30	4.55
sppcp	0.06	0.18	-0.47	0.44	0.05	0.20	-0.47	0.61	0.08	0.23	-0.55	0.86
smtmp	1.68	1.01	0.30	4.55	2.11	0.82	0.51	4.55	2.53	0.72	1.06	4.55
smpcp	0.03	0.18	-0.44	0.55	0.03	0.20	-0.47	0.61	0.06	0.24	-0.55	0.86
wttmp	1.32	0.59	0.30	3.11	1.82	0.73	0.49	3.62	2.22	0.99	0.49	4.55
wtpcp	0.10	0.18	-0.44	0.50	0.10	0.20	-0.47	0.61	0.12	0.22	-0.55	0.86
HadCM3-A1B emission scenario												
sptmp	1.91	0.79	0.81	4.00	2.61	0.85	0.96	4.73	3.14	1.25	0.96	6.22
sppcp	0.06	0.22	-0.56	0.87	0.10	0.26	-0.56	1.10	0.14	0.32	-0.56	1.16
smtmp	2.33	1.38	0.81	6.22	2.93	1.06	1.27	6.22	3.43	1.05	1.27	6.22
smpcp	0.00	0.21	-0.56	0.82	0.06	0.25	-0.44	1.10	0.13	0.31	-0.44	1.16
wttmp	1.89	0.75	0.81	3.92	2.58	0.83	0.81	4.73	3.15	1.25	0.81	6.22
wtpcp	0.09	0.23	-0.56	0.77	0.14	0.24	-0.33	1.10	0.18	0.30	-0.44	1.16
HadCM3-A2 emission scenario												
sptmp	1.60	1.05	-0.08	4.37	2.32	1.00	0.25	4.37	3.26	1.61	0.25	6.88
sppcp	0.04	0.19	-0.46	0.52	0.08	0.23	-0.54	0.72	0.09	0.30	-0.54	1.25
smtmp	2.10	1.73	-0.08	6.88	2.68	1.41	0.92	6.88	3.57	1.36	0.92	6.88
smpcp	-0.01	0.18	-0.54	0.50	0.04	0.21	-0.54	0.72	0.07	0.30	-0.54	1.25
wttmp	1.55	0.96	-0.08	4.23	2.21	1.05	-0.08	4.23	3.18	1.72	-0.08	6.88
wtpcp	0.10	0.19	-0.33	0.73	0.12	0.21	-0.54	0.73	0.14	0.29	-0.54	1.25

Note: We got data of monthly changes of temperature and precipitation for years of 2010 to 2099 from the IPCC data distribution center. In order to get seasonal changes of temperature and precipitation, we use the mean of their changes.

Table 5 Changes of Land Use Allocation and Cattle Stocking Rate

	Base	2010-2039	2040-2069	2070-2099
		HadCM3-B1 emission scenario		
Crop	0.60	-0.22	-0.28	-0.33
Pasture	0.29	0.28	0.35	0.41
Other land use	0.11	-0.06	-0.07	-0.08
Cattle stocking rate*(animal/acre)	0.25	-35.48	-41.86	-48.87
		HadCM3-A1B emission scenario		
Crop	0.60	-0.31	-0.38	-0.43
Pasture	0.29	0.39	0.46	0.52
Other land use	0.11	-0.07	-0.09	-0.09
Cattle stocking rate*(animal/acre)	0.25	-49.89	-58.01	-66.34
		HadCM3-A2 emission scenario		
Crop	0.60	-0.28	-0.35	-0.44
Pasture	0.29	0.35	0.43	0.53
Other land use	0.11	-0.07	-0.08	-0.09
Cattle stocking rate *(animal/acre)	0.25	-47.72	-54.63	-70.27

Note: For land use allocation, this table shows the changes of predicted probabilities that are calculated from the FMNL model with pooled sample and sub-regional dummies;

For cattle stocking rate, this table shows the predicted changes of cattle stocking rate that are derived from the OLS model with pooled sample.

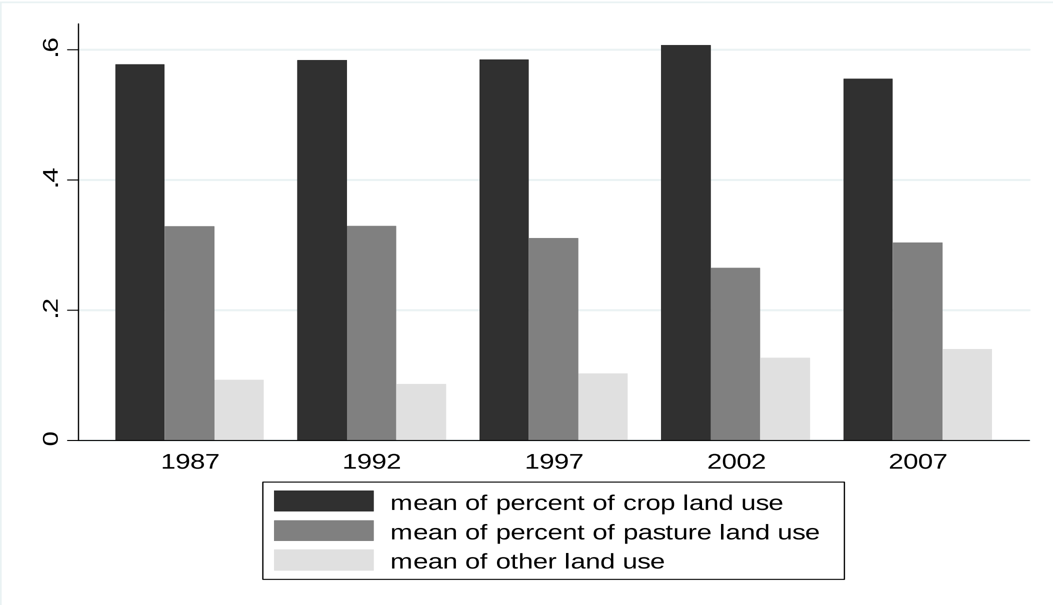

Figure 1 Trend of land use among cropping, livestock operation and other usage

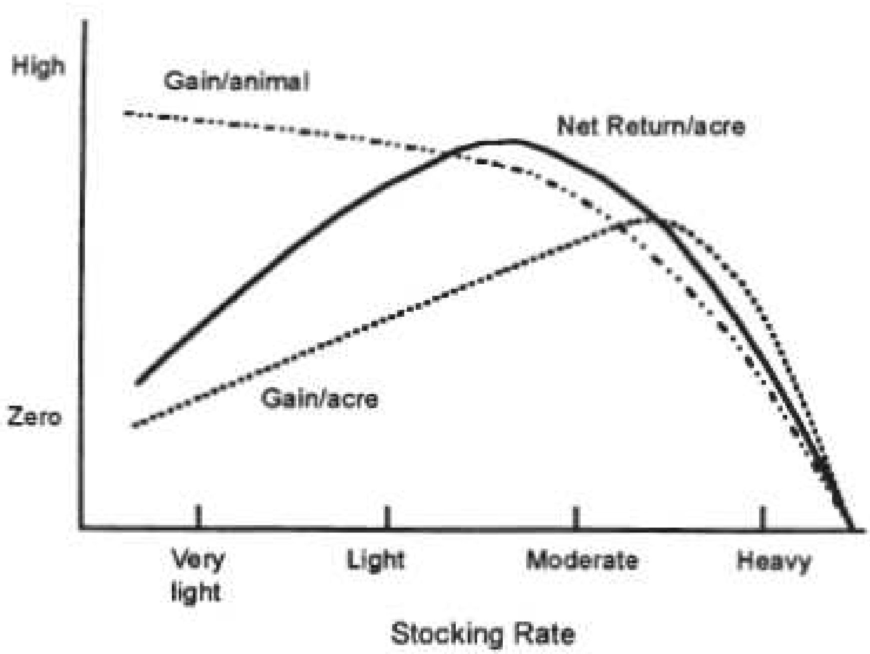

Figure 2 Influence of stocking rate on individual animal performance, gain per acre, and net return per acre.

(Source: Redfearn and Bidwell, http://pods.dasnr.okstate.edu/docushare/dsweb/Get/Rendition-2172/unknown)

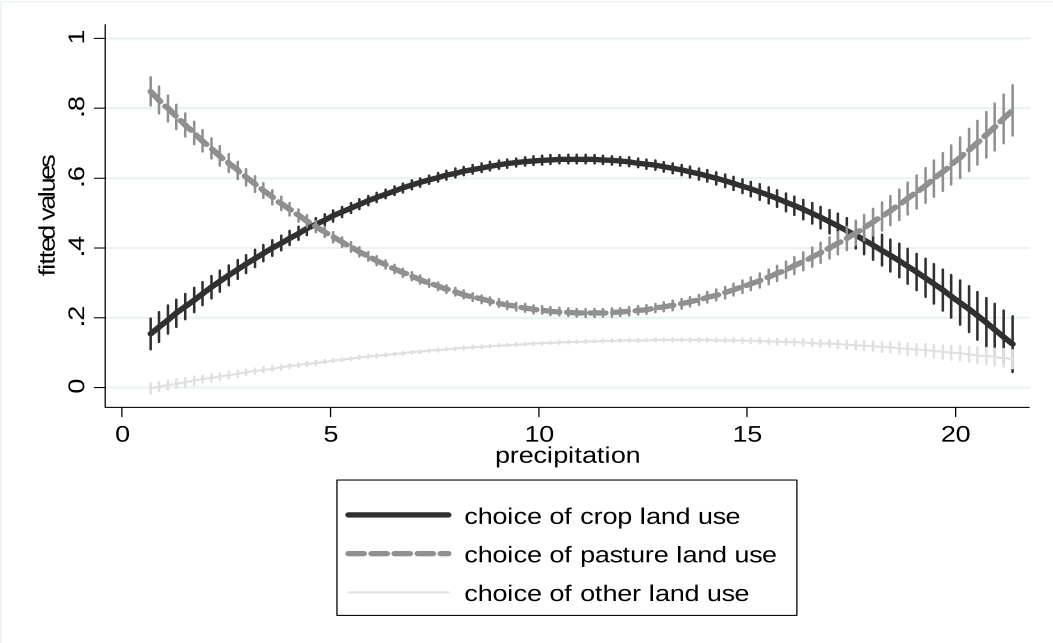

Figure 3 Probability of Land Use Allocation as Annual Mean Precipitation Varies

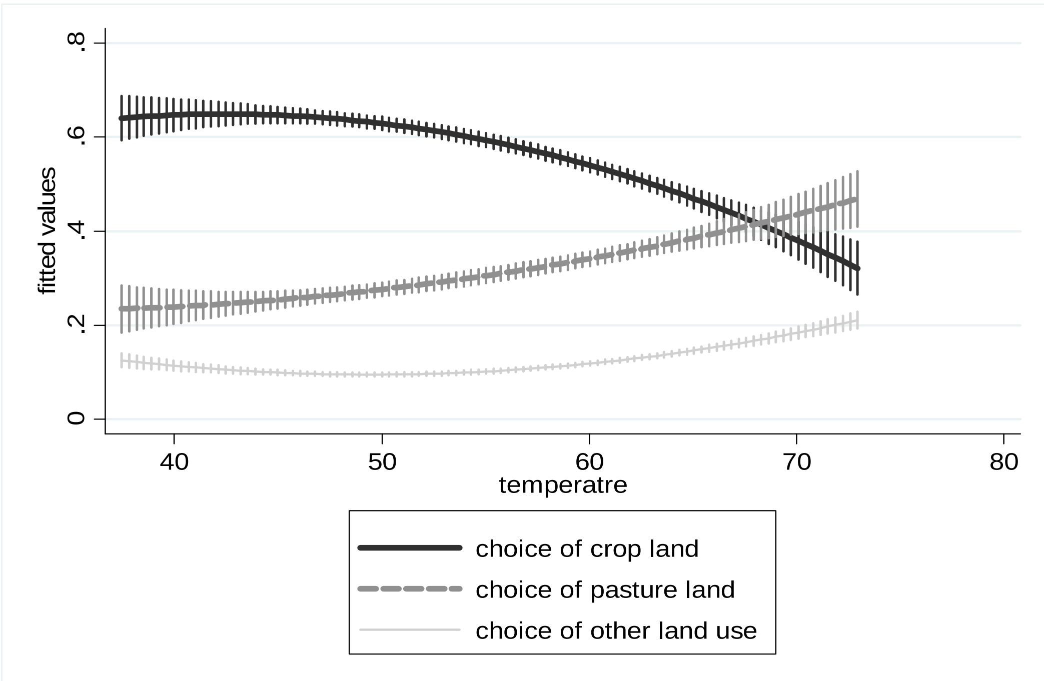

Figure 4 Probability of Land Use Allocation as Annual Mean Temperature Varies

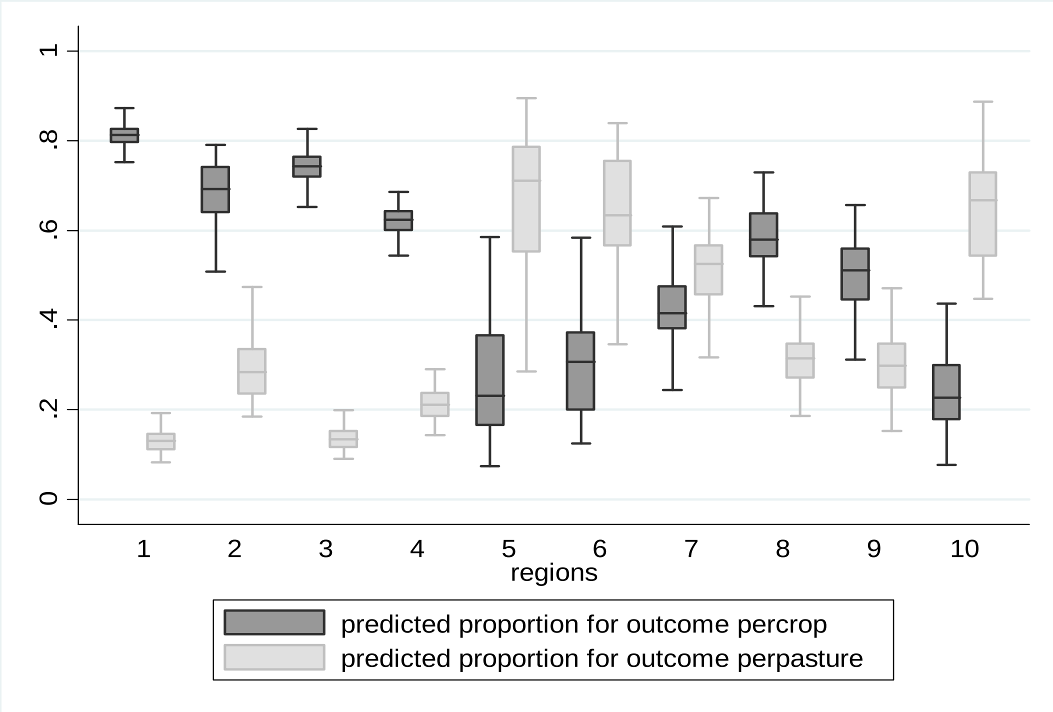

Figure 5 Probability of Land Use Allocation as Region Varies

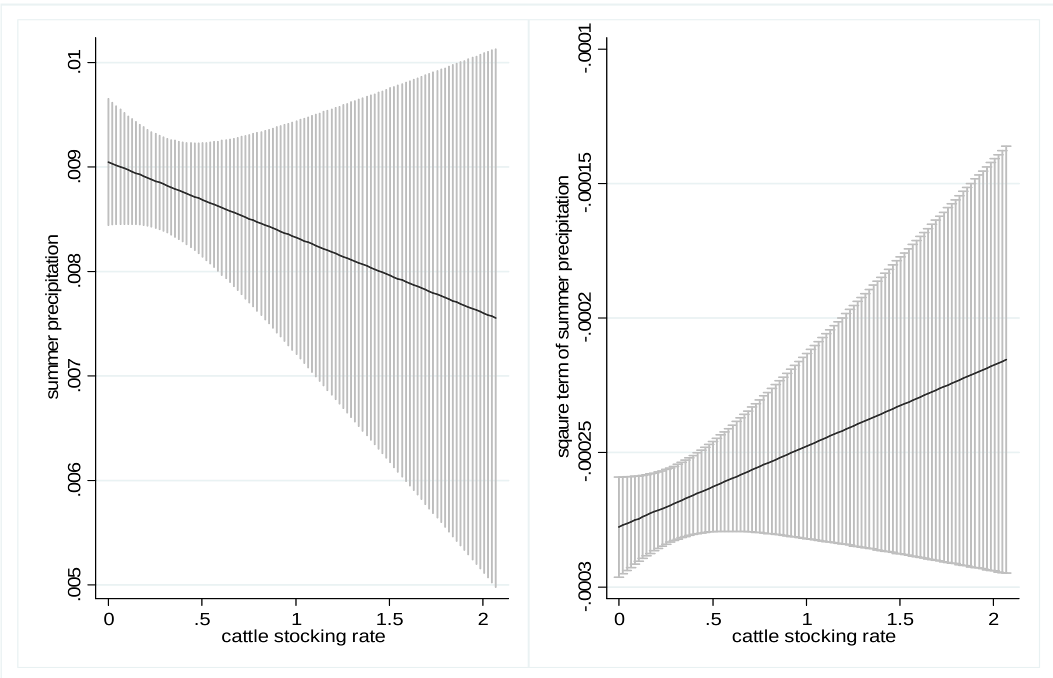

Figure 6 Summer Precipitation Effects on Cattle Stocking Rate

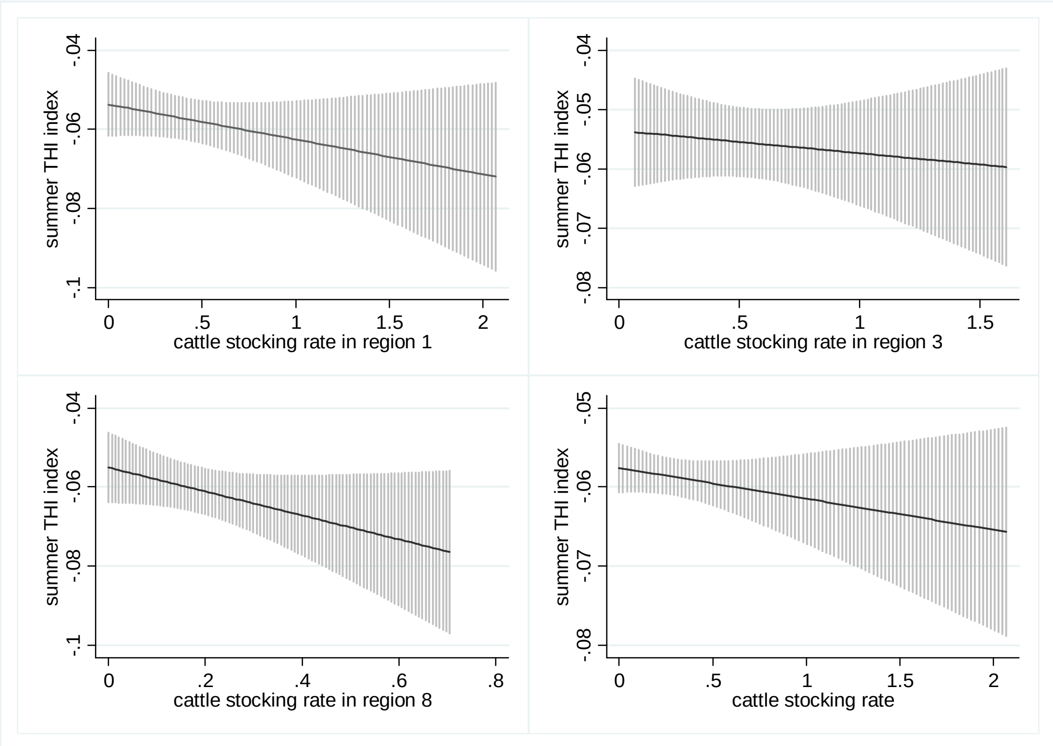

Figure 7 Summer THI Index Effects on Cattle Stocking Rate as Region Changes

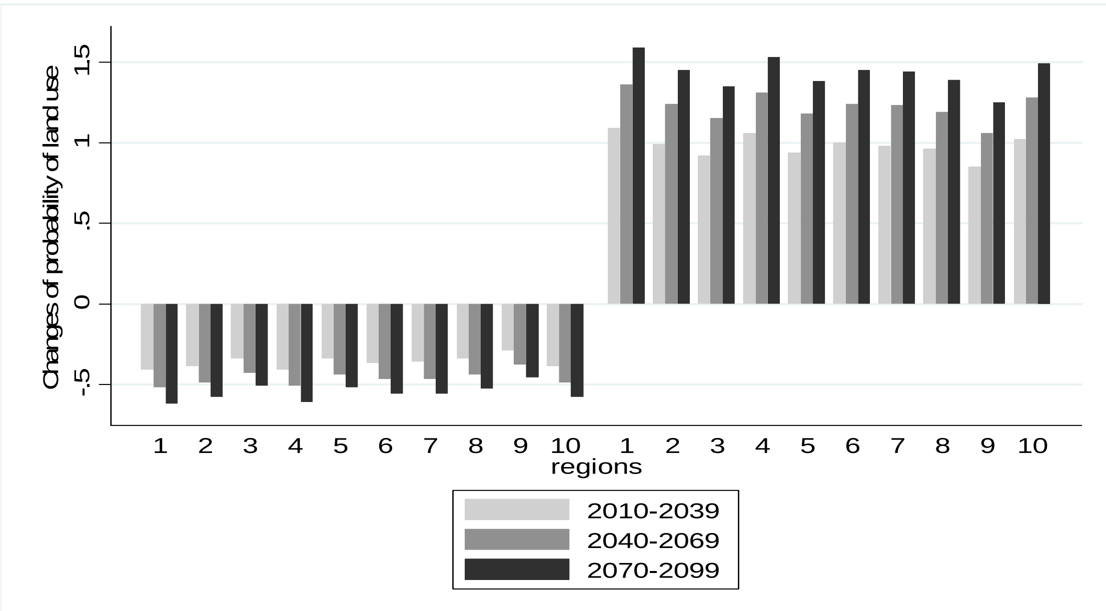

Figure 8 Changes of the probability of crop and pasture land use as Region Changes under B1 Scenario

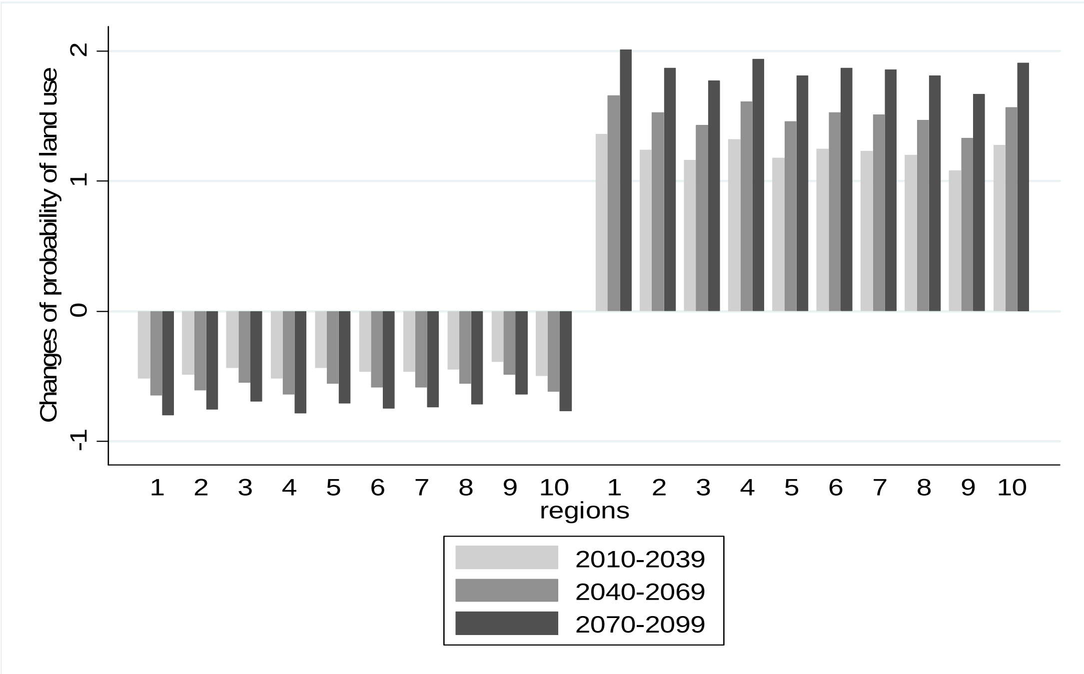

Figure 9 Changes of the probability of crop and pasture land use as Region Changes under A2 Scenario