Accounting for Land Use Adaptation to Climate Change Impacts on US Agriculture

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1. Introduction

According to the United Nations Intergovernmental Panel on Climate Change (IPCC) fifth assessment report (2013), climate change is predicted to increase temperatures, and alter precipitation and water supply patterns. Warming is likely to increase the productivity of crops relative to livestock in cool places but reduce crop productivity in relatively hot locations. Thus, adaptation strategies are likely necessary (Rose and McCarl 2008). Many strategies have co-benefits, however, in fact investments in agricultural adaptation represent a cost-effective mitigation strategy (Lobell et al., 2013).

The IPCC fifth assessment (2014) also reports projected declines in global agricultural productivity due to climate change have implications for food security among North Americans. Because the US is a major exporter, shifts in agricultural productivity here may have implications for global food security. However, Butler and Huybers (2012) claim the North American agricultural industry has the adaptive capacity to off-set projected yield declines and capitalize on opportunities under 2° warming. Their study projects a reduction in US corn yield loss from 14% to 6% with 2° warming, with spatial shifts in varietal selection (not accounting for variability in temperature and precipitation).

In comparison to crop production, considerably less work has been published on observed impacts for livestock (IPCC, 2014). The relative lack of evidence reflects a lack of study in this topic, but not necessarily a lack of real-world impacts of observed climate trends.

The objective of this study is to analyze how the US farmers adapt their land use such as farmland area and type to climate change. It is crucial to understand farmers' behavior in response to a changing climate because land use planning has significant capacity to reduce risks from current climate and climate change (IPCC, 2014).

2. Literature Review

There has been active debate on climate change impacts on the US agriculture. Robert Mendelsohn, William D. Nordhaus and Daigee Shaw (1994), hereafter MNS, propose Ricardian analysis to measure the economic impact of climate change on farmland values in the US. The Ricardian approach is based on comparative static estimates of how equilibrium land rents will change when a one-time instantaneous climate change is introduced. It estimates the impact of climatic, socio-economic, and geophysical variables on land values and farm revenues on the basis that the production function for crops will shift as climate changes. It assumes that farmers first take climate as given then decide what to grow, with what inputs, and in what way, or decide to convert land to other uses entirely (Reinsborough, 2003). Using cross sectional data on climate, farmland values, and other economic and geophysical data, they find that higher temperatures in all seasons except autumn reduce average farm values, while more precipitation outside of autumn increases farmland values. By applying the model to a global-warming scenario, they show a significantly lower estimated impact of global warming on U.S. agriculture than the traditional production-function approach (Adams et al., 1988, 1990; Adams, 1989; Rosenzweig and Parry, 1994). Furthermore, the study suggests that, in one case even without CO2 fertilization, global warming may have economic benefits for agriculture.

There have been studies that raise a question on the particular implementation in MNS. Wolfram Schlenker, W. Michael Hanemann and Anthony C. Fisher (2005), hereafter SHF, summarize those criticisms as followings: (a) the hedonic approach cannot be used to estimate dynamic adjustment costs; (b) the results are not robust across different weighting schemes; and (c) the inadequate treatment of irrigation in the analysis might bias the results (William R. Cline, 1996; Robert K. Kaufmann, 1998; Darwin, 1999; John Quiggin and John K. Horowitz, 1999). The first criticism alludes to the fact that some farmers might not find it profitable to switch to new cropping patterns given their existing crop-specific fixed capital. Climate change will occur only gradually, however, and most costs can thus be seen as variable. In their paper, they focus on the latter two points, especially the role of irrigation. Previous comments have raised theoretical concerns about potential sources of misspecification related to irrigation. Once irrigation is accounted for, they show that results also become robust across weighting schemes or models. Elsewhere they extend the analysis in various directions: construction and use of climate variables tied more closely to agronomic findings; development of more accurate measures of both climate and soil conditions; adjustment for spatial correlation of the error terms in a hedonic regression; and use of recent climate scenarios that go beyond the traditional assumption of uniform impacts across regions of a doubling of greenhouse gas concentrations in the atmosphere (Schlenker et al., 2004). Their results show that, when the model is estimated for dryland non-urban counties alone, the estimates of climate impacts on the US agriculture are unambiguously negative. Since the necessary data are not available for irrigated areas, they confine their analysis to dryland areas.

Interestingly, two innovative studies by MNS and SHF controversially show different signs on their resulting estimates. In the recent study by Massetti et al. (2013), they argue that hypotheses in SHF fail when accurate measures of degree days are used. Also, Massetti and Mendelsohn (2012) examine the promise of using panel data to estimate the Ricardian model. The panel data offers an improvement over single cross sections because the repeated observations allow the researcher to disentangle annual from long term effects. The models are more likely to be properly specified and they do a good job of stabilizing climate estimates across the years.

Despite of rich literature on the impact of climate change on US agriculture, most studies assume that farmland area does not change. However, farmers should adapt their farmland area to climate change and choose whether they stop farming in existing farmland or start farming in new land. Thus, climate impact estimates of previous literature might be biased. There are a few studies on farmers’ adaptation to climate change in the US. Mendelsohn et al. (1996) explore a new application of the Ricardian method capturing how climate affects both the per acre value of farms and how much land is farmed. They conclude the new aggregate farm model does a better job of forecasting behavior outside the range of the data compared to earlier Ricardian models. Mu et al. (2006) study possible adaptations to climate change in terms of pasture and crop land use and stocking rate in the US and find that as temperature and precipitation increases agricultural commodity producers respond by reducing crop.

In this paper, I analyze the impact of climate change on farmland values and areas in the US allowing farmers to adapt their land use such as farmland area and land type. There are three main contributions this paper makes to the existing literature. First, this study accounts for farmers' land use adaptation to climate change impacts on US agriculture and provide new estimates of climate impacts on US agriculture. Second, in this paper, I trace out heterogeneous impacts of climate change on different regions of the US by including the whole country as an area of study. SHF and Massetti et al. (2013) limit their study area to farmland in the Eastern United States which is a poor proxy for farmland across the whole country. Third, I include new climate variables such as surface wind speed and direction, surface pressure, solar radiation and surface moisture as well as diurnal temperature variance. Although diurnal temperature variance has been considered to affect crops (Mendelsohn and Dinar, 2009), previous literature has not been able to calculate actual variance of diurnal temperature due to lack of historical climate data at hourly level. To my best knowledge, this is the first study to analyze the impact of climate change on the entire US agriculture with farmers' land use adaptation in a spatially and temporally detailed manner.

3. Methodology

Ricardian method used in MNS analyzes the impact of climate change on farmland values in the US. Massetti and Mendelsohn (2012) and Massetti, Mendelsohn and Chonabayashi (2013) use panel data set to improve the Ricardian model. A Ricardian model of the relationship between land value and climate is specified as below:

$$V_{it} = \beta h(M_i) + \gamma X_{it} + \theta Z_i + \psi_i + \varepsilon_{it} \tag{1}$$

where V is log of the land value per hectare at time t for county i, h(·) is a genetic function of the vector of climate variables M, X is a set of socio-economic variables and an irrigation variable that vary over time, Z is a set of geographic and soil characteristics at county centroids such as latitude, elevation, and distance from major metropolitan areas that are fixed over time, ψ is a county fixed effect, and ε is assumed to be a random component. Subscript i and t represent county and time respectively. β, γ, and θ are coefficient vectors. β provides sensitivity information on the sensitivity of aggregate farm value to climate and can be used to estimate the welfare impact of climate change. Several studies found that a loglinear functional form fits agricultural land values more closely than a linear model (Mendelsohn and Dinar 2003, Schlenker, Hanemann and Fisher 2005; 2006; Massetti and Mendelsohn 2011; 2012).

Mendelsohn et al. (1996) assume that the land which farmers could farm is also sensitive to climate in this paper. They use aggregate farm value instead of the farmland value per hectare in order to account for farmers' land use adaptation to climate change. By examining how aggregate land value shifts with changes in the environmental variable of interest, they measure the impacts through changes in the present value of net revenue. Aggregate farm value is the product of the arable land times the value per hectare. Climate thus has two impacts on aggregate land value affecting the total amount of land farmed and the value per hectare. Looking at the aggregate value has both effects, but we cannot say much about adaptation since they are entangled.

In this study, I look at the land in farms separately and model farmers' land-use decision. I assume farmers decide allocation of their land to cropland and pasture or other use. The theoretical basis for my empirical aggregated land use share model has been widely analyzed in the literature (Lichtenberg 1989, Stavins and Jaffe 1990, Wu and Segerson 1995 and Plantinga 1996, and Miller and Plantinga 1999, Chakira and Le Gallob 2013). The share of farmland is defined as the fraction of each land use in each county. Formally, the observed share of land use k in county i at time t is expressed as:

$$s_{kit} = p_{kit} + u_{kit} \tag{2}$$

where s_{kit} is the observed share of land allocated to land use k in county i at time t, and p_{kit} is the expected share of land allocated to land use k in county i at time t. The observed land allocation at time t may differ from the optimal allocation due to random factors, u_{it}, such as bad weather or unanticipated price changes. These random events are assumed to have a zero mean.

I assume a logistic specification for the share function as follows:

$$p_{kit} = \frac{e^{\delta_k W_{kit}}}{\sum_{j=1}^{K} e^{\delta_j W_{jit}}} \tag{3}$$

where W_{kit} are explanatory variables pertaining to land use k in county i at time t, β_k is a vector of unknown parameters that measures the effect of explanatory variables on the expected shares.

The natural logarithm of each observed share normalized on a common share (s_{Kit}) is approximately equal to:

$$\tilde{y}_{kit} = ln(s_{kit}/s_{Kit}) = \delta_k W_{it} \tag{4}$$

The model in Equation (4) above is identified if $\delta_K = 0$. By substituting a set of dependent variables in the equation (1) to W_{it}, I obtain the resulting reduced-form equation for $\tilde{y}_{kit}$ becomes as below:

$$\tilde{y}_{kit} = ln(s_{kit}/s_{Kit}) = \beta_k h(M_i) + \gamma_k X_{it} + \theta_k Z_i + \psi_{ki} + \varepsilon_{kit} \tag{5}$$

In this paper, we consider three land uses (K=3): (1) cropland (c), (2) pasture (p), (3) other uses (o). The shares s_c, s_p and s_o of the three land-use classes sum up to one, which implies restrictions on the parameters. I choose to drop one equation and to consider the "other uses" (s_o) category as a reference from which to construct two dependent variables as $ln(s_c/s_o)$ and $ln\left(s_p/s_o\right)$.

For climate variables, I include seasonal means of temperature and precipitation and their squared terms. The seasonal climate is the arithmetic average of climate variables in winter (December, January, February), spring (March, April, May), summer (June, July, August) and autumn (September, October, November). I include quadratic terms of seasonal variables due to non-linear effects of the climate variables (Mendelsohn, Nordhaus, and Shaw 1994; Mendelsohn and Dinar 2003; Schlenker, Hanemann, and Fisher 2005; Massetti and Mendelsohn 2011; 2012). The resulting equation for climate variables is as follows:

$$h(M_i) = \sum_s T_{is} + T_{is}^2 + P_{is} + P_{is}^2 \tag{6}$$

where T and P are seasonal temperature and precipitation respectively, subscript s represents season (winter, spring, summer and autumn).

After estimating the equations, I predict future cropland and livestock shares as follows:

$$\hat{y}_{kit} = \hat{\beta}_k h\left(\dot{M}_i\right) + \hat{\gamma}_k \bar{X}_i + \hat{\theta}_k Z_i + \hat{\psi}_{ki} \tag{7}$$

where $\hat{\beta}_k$, $\hat{\gamma}_k$, $\hat{\theta}_k$ and $\hat{\psi}_{ki}$ are vectors of estimated coefficients from the equation (5), $\dot{M}$ are future climate variables and $\bar{X}$ is a set of mean socio-economic variables over time.

4. Data

I use a balanced panel using United States Agricultural Census data for 1978, 1982, 1987, 1992, 1997 and 2002. I use the following time varying socio-economic variables: income per capita, population density, population density squared.[1] I also control for a set of geographic, time invariant characteristics at county centroids: latitude, elevation, and distance from major metropolitan areas. We use USGS data to estimate the average annual surface and ground water use per hectare of farmland. Finally, we control for some important soil characteristics: salinity, percentage of soil subject to flooding, percentage of land with low drainage, soil erodibility, average slope length factor, percentage of sand and of clay, minimum available water capacity, and permeability.

We rely on the 1971–2000 monthly precipitations and mean temperature normals (mean) computed by the National Climatic Data Center for 7,467 weather stations in the contiguous 48 States. Following Mendelsohn, Nordhaus and Shaw (1994), we interpolate between stations using a local quadratic climate surface as a function of longitude, latitude, elevation and distance from coastline. For each county, we calculate the weather surface using the weather stations within 500 miles. The data is weighted to give nearby stations more weight.

5. Results

- Table 1: Regression results
- Figure 1: Mean shares of cropland and pasture for 1978-2002
- Figure 2: Predicted shares of cropland and pasture (current climate)
- Figure 3: Predicted changes in cropland and pasture shares (uniform climate scenario)
- Figure 4: Predicted changes in cropland and pasture shares (NCPCM climate scenario)

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[1] These variables are the same as ones used by Massetti and Mendelsohn (2011; 2012).

- Figure 5: Predicted changes in cropland and pasture shares (HADCM climate scenario)
- Figure 6: Predicted changes in cropland and pasture shares (MIMR climate scenario)

6. Conclusion

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Table 1: Regression results

	(1) Cropland	(2) Pasture
Income per capita	-0.0015	-0.017
	(0.0055)	(0.011)
Population density	3.08***	3.11**
	(0.67)	(1.27)
Pop density squared	-2.42***	-2.50***
	(0.40)	(0.77)
Share of greenhouses	-0.34***	-0.14
	(0.094)	(0.15)
Year 1982	-0.16***	-0.20***
	(0.020)	(0.040)
Year 1987	0.097***	0.044
	(0.023)	(0.049)
Year 1992	0.23***	0.21***
	(0.031)	(0.065)
Year 1997	-0.074*	-0.16*
	(0.040)	(0.083)
Year 2002	-0.33***	-0.38***
	(0.049)	(0.10)
Winter temperature	-0.46*	0.47***
	(0.27)	(0.18)
Winter temp squared	-0.0035	0.040***
	(0.0088)	(0.0089)
Spring temperature	-0.99*	0.85
	(0.52)	(0.73)
Spring temp squared	0.075**	-0.079*
	(0.034)	(0.045)
Summer temperature	0.43	-1.80*
	(0.96)	(1.08)

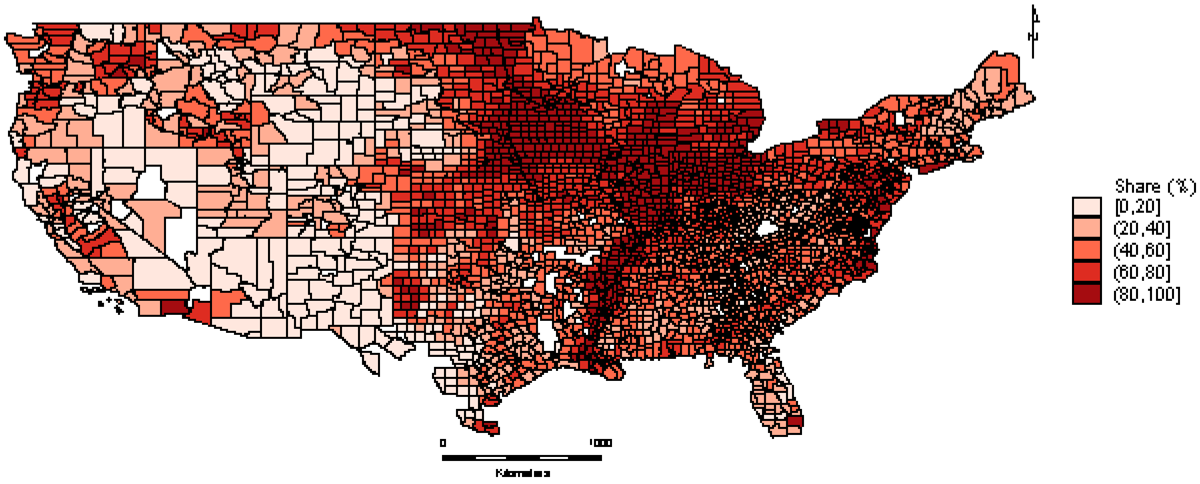
Summer temp squared	-0.023	0.059**
	(0.025)	(0.029)
Autumn temperature	2.75***	-0.88
	(0.81)	(1.36)
Autumn temp squared	-0.068*	0.011
	(0.037)	(0.057)
Winter precipitation	-0.0034	0.019
	(0.018)	(0.021)
Winter prec squared	-0.000082	-0.00023***
	(0.000060)	(0.000065)
Spring precipitation	0.10**	0.29***
	(0.041)	(0.057)
Spring prec squared	-0.00046***	-0.00088***
	(0.00017)	(0.00018)
Summer precipitation	-0.033	-0.086*
	(0.030)	(0.045)
Summer prec squared	0.00011	0.00014
	(0.00014)	(0.00019)
Fall precipitation	-0.070	-0.22***
	(0.043)	(0.043)
Fall prec squared	0.00051**	0.0010***
	(0.00021)	(0.00022)
Flood	-0.90***	0.062
	(0.28)	(0.27)
Low drainage	-0.10	-1.00*
	(0.32)	(0.53)
Soil erodibility	1.79	8.10***
	(1.43)	(1.74)
Length of slope	1.82***	0.54
	(0.49)	(0.67)
Sand	1.10***	-0.093
	(0.42)	(0.59)

Clay	1.17	2.84***
	(0.95)	(1.00)
Low water capacity	7.78***	1.06
	(2.40)	(3.04)
Low permeability	-0.19	0.13
	(0.13)	(0.14)
Latitude north	0.41***	-0.033
	(0.13)	(0.16)
Elevation	3.40***	0.34
	(1.02)	(1.44)
Surface water	-0.11**	-0.055
	(0.043)	(0.046)
Adjusted R-squared	0.837	0.849
Observations	11013	11013

* p<0.10, ** p<0.05, *** p<0.01

Note: The dependent variable is a share of cropland and pasture divided by a share of other land uses respectively. Standard errors are within parentheses.

Figure 1: Mean shares of cropland and pasture for 1978-2002


Cropland

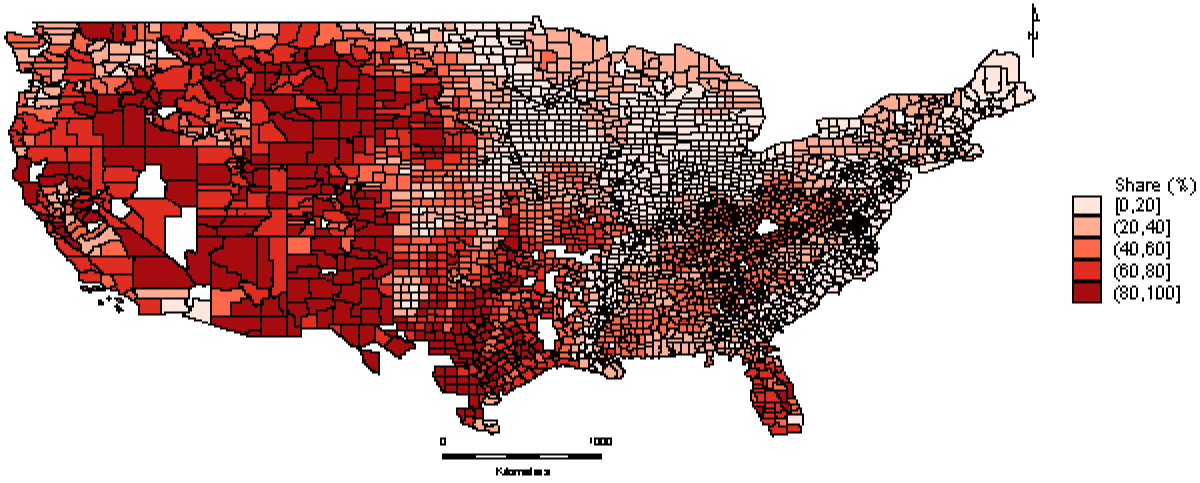
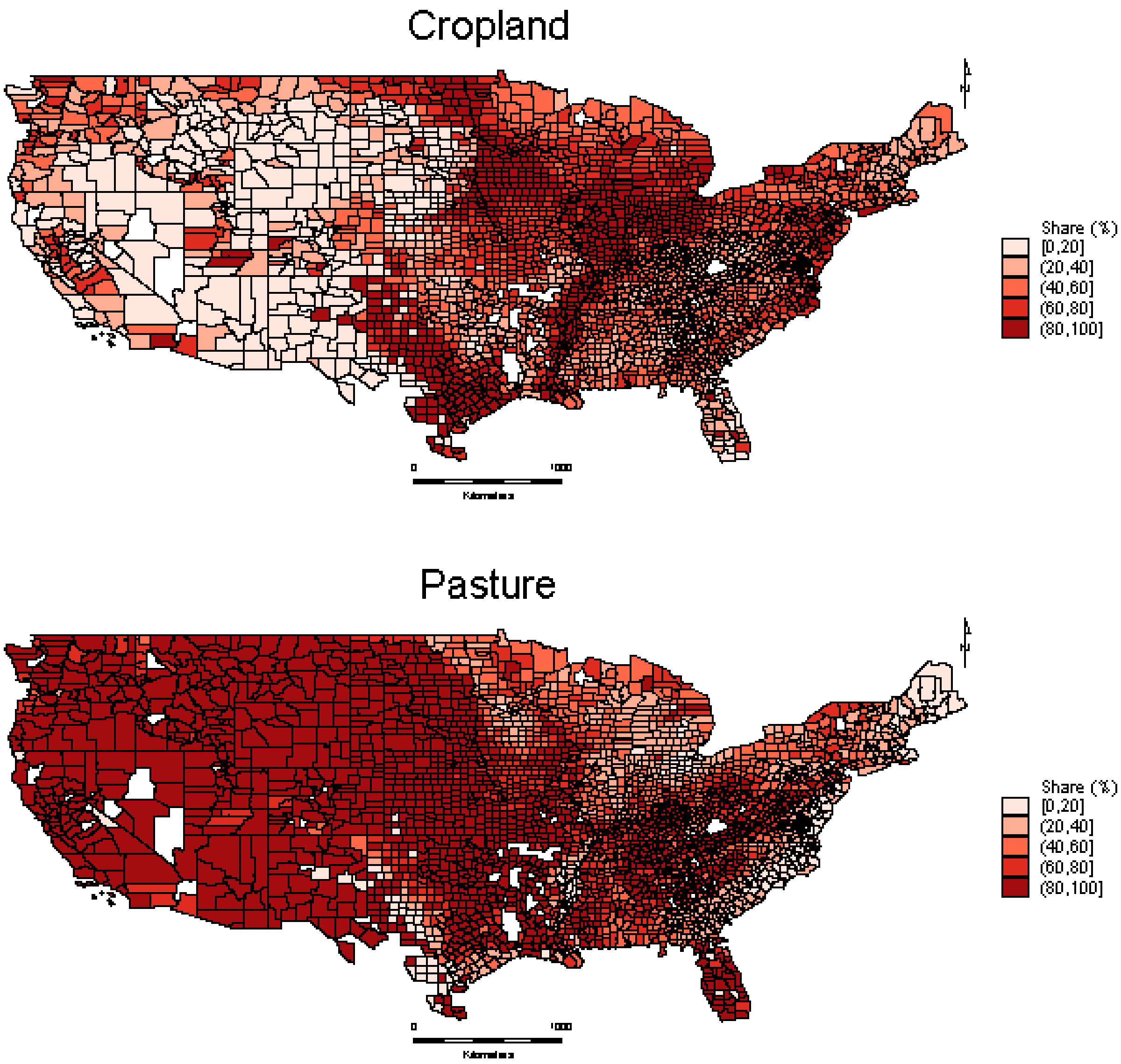

Pasture

Figure 2: Predicted shares of cropland and pasture (current climate)



Cropland

Pasture

Figure 3: Predicted changes in cropland and pasture shares (uniform climate scenario)

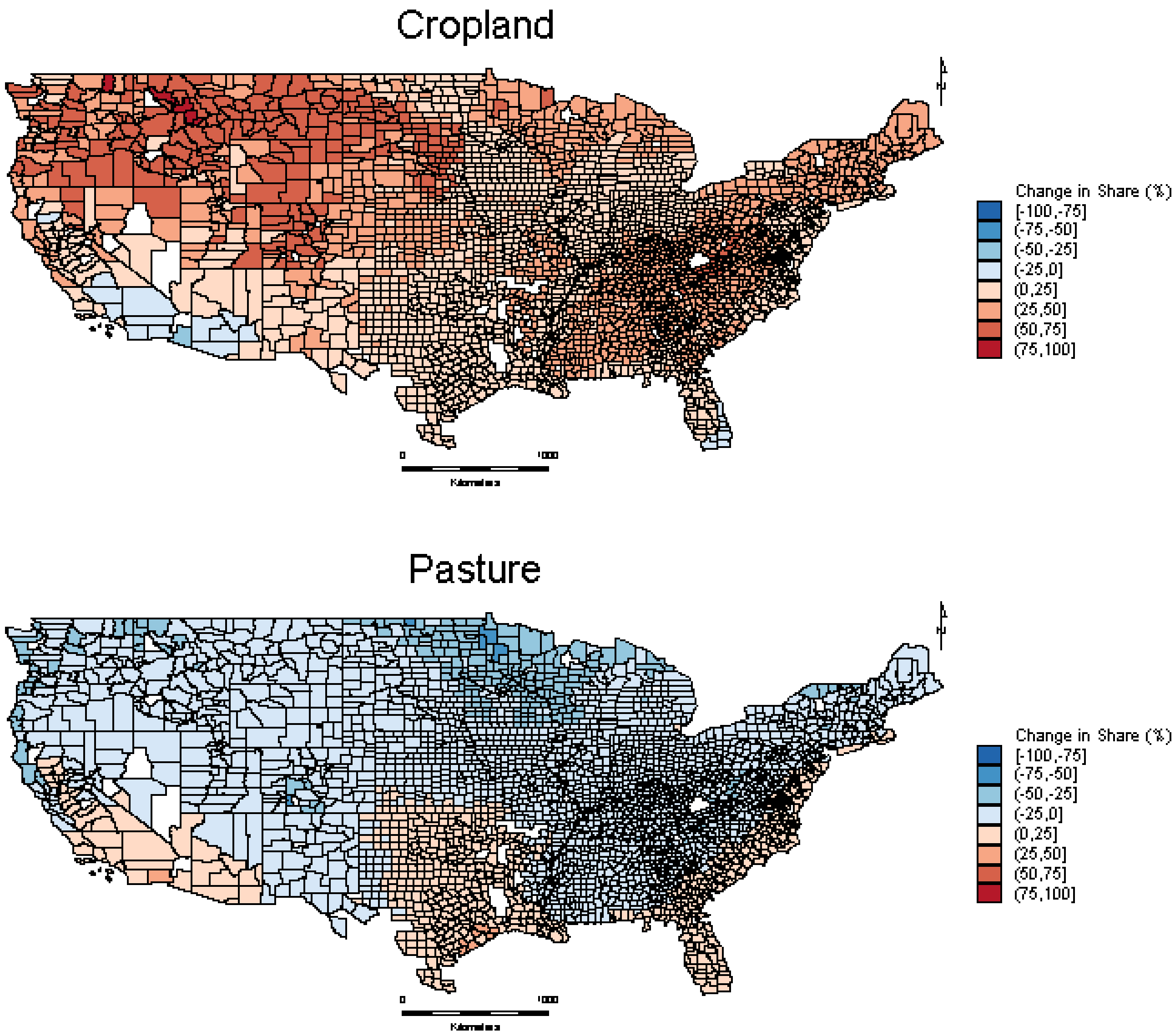


Figure 4: Predicted changes in cropland and pasture shares (NCPCM climate scenario)

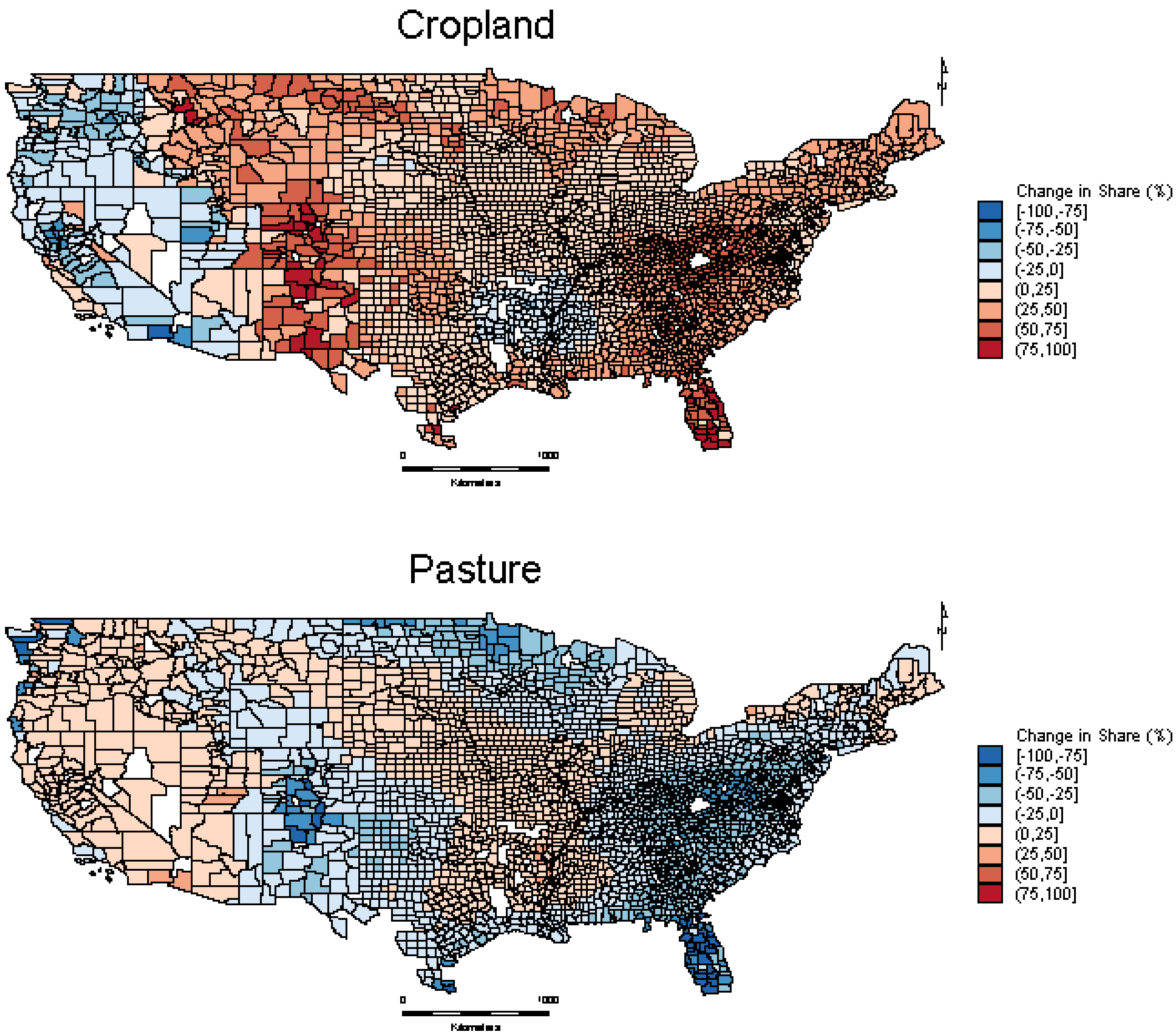
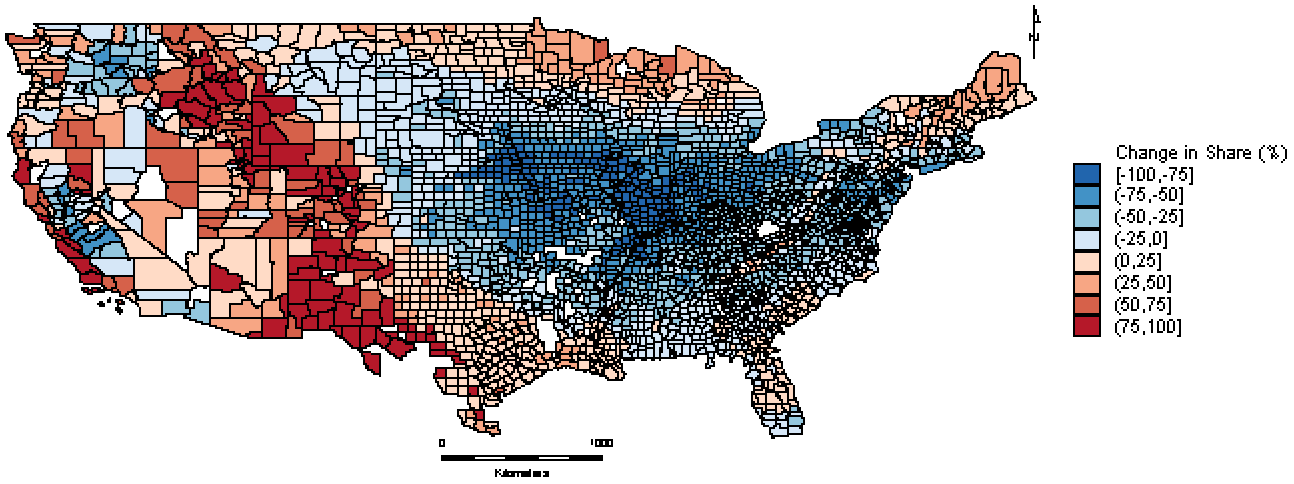
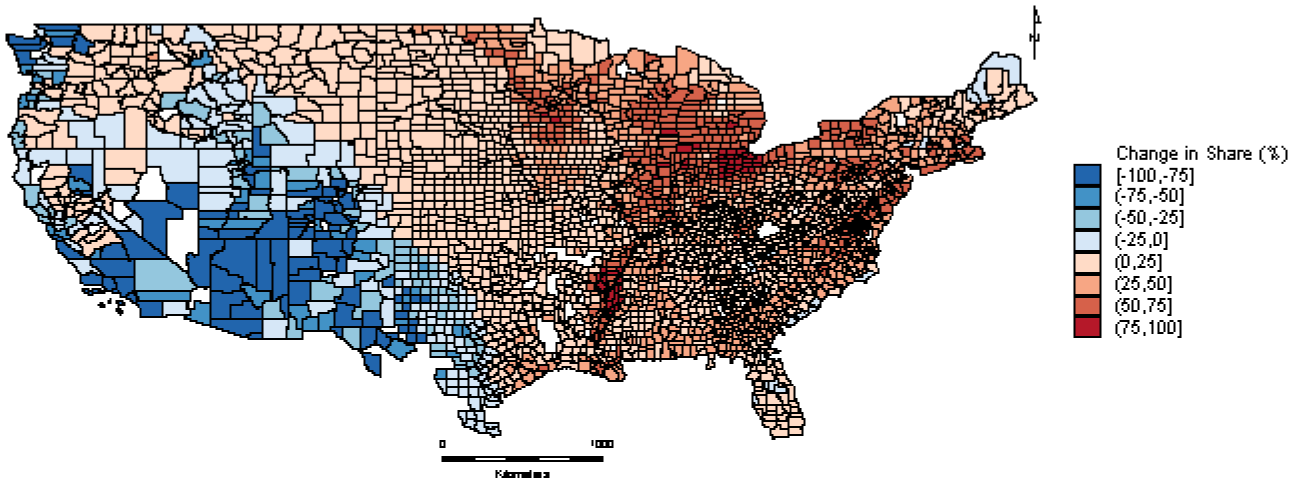


Figure 5: Predicted changes in cropland and pasture shares (HADCM climate scenario)



Cropland



Pasture

Figure 6: Predicted changes in cropland and pasture shares (MIMR climate scenario)