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Adaptation to Climate Change via Adjustment in Land Leasing: Evidence from Dryland Wheat Farms in the U.S. Pacific Northwest

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Abstract:

This paper investigates how dryland wheat farm operators adapt to climate through the use of land leasing in the U.S. Pacific Northwest region. Using a farm-level dataset from the U.S. Census of Agriculture, we build a statistical relationship between climate and leased acreage for dryland wheat farms. We find that a warmer and wetter climate reduces leased dryland wheat farmland, suggesting that land leasing is a potential strategy for adaptation to future climate. Using climate projections from 20 global climate models, we predict that, by 2050, leased acreage for dryland wheat farms on average will decline by 23% and 29% relative to 2012 levels under the medium and high greenhouse gas emission scenarios, respectively.

Keywords: Land Leasing, Climate, Climate Change Adaptation, Wheat

JEL: Q15, Q54, C21

1. Introduction

Increases in temperature, precipitation variability and extreme weather event frequency have been observed and are expected to continue to evolve in the future (IPCC 2014). Such changes in climate have been found to impact crop yield, farmland value, and farm net return (Mendelson, Nordhaus and Shaw 1994; Deschenes and Greenstone 2007; Lobell, Cahill and Field 2007; Schlenker and Roberts 2009; Burke and Emerick 2016). Globally, the Intergovernmental Panel on Climate change (IPCC) assessment indicates that, on average, projected climate change will reduce temperate region wheat yields by 5% in the absence of adaptation (IPCC 2014).

A growing body of literature has examined potential adaptations to climate change through changes in management practices and policies, e.g., planting dates, irrigation technologies, crop insurance, agricultural land use, cropping systems and fallow rotation (Negri, Gollehon and Aillery 2005; Ortiz-Bobea and Just 2013; Annan and Schlenker 2015; Olen, Wu and Langpap 2016; McCarl, Thayer and Jones 2016; Antle et al. 2017; Mu et al. 2017; Zhang, Mu and McCarl 2017). A less studied possible adaptation involves use of land leasing (Eskander and Barbier 2016). Leased land is a means of sharing production risk with land owners, and changes in climate may alter the extent of leasing and the type of lease arrangements. According to the 2012 Census of Agriculture, 78% of dryland wheat farms in the U.S. Pacific Northwest region leased some land, among which 74% had cash rent leases and 69% crop share leases (some farms used a mixture of both).

A variety of aspects of the agricultural land leasing market have been studied by agricultural economists including, e.g., property right insecurity (Myyrä et al. 2005; Maddison 2007; Yegbemey et al. 2013), land tenancy (Stiglitz 1974; Allen and Lueck 1992; Paulson and Schnitkey 2013), and farmland rental rates (Breustedt and Habermann 2011; Ciaian and Kancs 2012; Kirwan and Roberts 2014). In addition, Eskander and Barbier (2016) studied the effects of natural disasters on Bangladesh farmers' land leasing decisions, and found that farmers increasingly use leased land as losses from floods and storms rise. However, their study did not incorporate a general set of climate conditions and thus cannot reveal how farmers would adjust their land leasing decisions in response to changes in temperature and precipitation as well as their variability, and thus we will provide such an extension.

We do this using farm-level land leasing data for US Pacific Northwest dryland wheat farms from the U.S. Census of Agriculture. We estimate the effects of 5-year moving averages of growing season precipitation and temperature as well as climate variability on the extent of leased acreage and the type of lease. Using estimated coefficients, we then predict changes in leased acreage for dryland farms from 2012 to 2050 based on 20 IPCC global climate model projections under two greenhouse gas emission scenarios.

2. Estimation strategy

We apply the spatial analogue approach (Adams et al. 1998) in a panel data form to estimate a relationship between leased farmland acreage and climate. Therein we use spatial and temporal variation in leasing as associated with climate conditions to identify the effects of climate on leasing. The estimation equation is given by

(1) $$A_{\mathrm{it}} = \alpha_0 + \theta_{\mathrm{st}} + \mathrm{f}(\mathbf{c}_{\mathrm{it}}, \boldsymbol{\beta}) + \boldsymbol{\gamma}\boldsymbol{X}_{\mathrm{it}} + \boldsymbol{\delta}\boldsymbol{e}_i + \varepsilon_{\mathrm{it}}$$

where *i* represents an individual wheat farm, *t* is a census year, and *s* indicates the state where farm *i* is located. A_{it} is the acreage of leased farmland on farm *i* in year *t*. $\mathbf{c}_{\mathrm{it}}$ is a vector of climate conditions. $\boldsymbol{X}_{it}$ is a vector of socio-economic variables that characterize farm operator *i* (these characteristics are discussed below). $\boldsymbol{e}_{\mathrm{i}}$ is a vector of soil variables for the region where farm *i* is located. θ_{st} is a state by year fixed effect, and $\varepsilon_{\mathrm{it}}$ is a disturbance term. α_0, θ_{st}, $\boldsymbol{\beta}$, $\boldsymbol{\gamma}$ and $\boldsymbol{\delta}$ are parameters to be estimated.

We use the spatial analogue approach because we cannot observe temporal changes in climate of the magnitudes implied by the climate change projections. Thus, we use land leasing over space and time where across the sample climate conditions show sufficient variation to infer acreage responses of leased farmland to future climate. The spatial analogue approach has been repeatedly applied in the climate change impact assessment literature to address such an issue (e.g., Mendelsohn, Nordhaus and Shaw 1994; Lobell, Cahill and Field, 2007; McCarl, Villavicencio and Wu 2008; Schlenker and Roberts 2009; Mu, McCarl and Wein 2013).

To capture the non-linear response of leased farmland acreage to changes in climate, we estimate equation (1) with a quadratic specification for the climate variables, including 5-year moving averages of growing season total precipitation and average temperature and their squared terms as well as climate variability measures for precipitation and temperature in the form of the moving 22-year coefficients of variation.

We focus on the estimation of climate impacts on leased acreage for dryland farms. Irrigated farms are not considered in this paper because farmers' irrigation decisions on irrigation incidence and technologies are influenced by non-climate factors such as economic and physical water scarcity and water supply institutions (Olen, Wu and Langpap 2016). More importantly, irrigation water in the PNW does not necessarily arise from local supplies, with say, supplies drawn from the Columbia River originating in remote locations so local precipitation is not relevant (for further discussion on irrigation see Schlenker, Hanemann and Fisher 2005).

Also, we run two separate regressions using equation (1) for tenants with cash rent leases and with crop share leases to differentiate climate impacts on leased farmland acreage under the two types of land leases. This is because farm operators using different types of lease arrangements including cash rent and crop share, may behave differently related to leasing decisions and climate reactions. As predicted by economic theory, tenants under crop share leases will have lower risk and expected return than under cash rent leases (Paulson and Schnitkey 2013).

In addition, we do not include wheat and input prices in our estimation because these prices do not vary much across the PNW region within the same census year. Instead, we include state by year fixed-effects to capture price effects.

3 Data

The study area spans Oregon, Washington and Idaho in the U.S. Pacific Northwest. Our main data source is the U.S. Census of Agriculture for the years 2002, 2007 and 2012, which covers almost all farms in this region (National Agricultural Statistics Service 2002, 2007, 2012). We use data on dryland wheat farms with farmland more than 50 acres and associated ZIP codes to link the farm data to soil and climate data.

The census data used in this study include farm-level measures of leased farmland acreage, whether the annual farm revenue is over $250,000, and the share of land enrolled in the Conservation Reserve and Wetland Reserve Programs (CRP and WRP). We also include farmer characteristics in the form of years of farming experience and major job occupation. The resultant data set covers 10,135 dryland wheat farms over the three census years. Panel A in Table 1 reports summary statistics on these socio-economic variables.

Soil data come from the Gridded Soil Survey Geographic (gSSURGO) database (Natural Resources Conservation Service 2015). ZIP code level soil variables are generated by taking the acreage-weighted average across all gSSURGO polygons within the ZIP code. Soil variables used are land slope, amount of soil organic matter, sand and clay contents, and soil loss tolerance factor. Panel B in Table 1 reports summary statistics on these soil variables.

Weather data are drawn from Abatzoglou and Brown (2012)'s construction of a gridded, 4-km resolution, meteorological dataset. We compute the total precipitation and average temperature over the September-June winter wheat growing season at the ZIP code level and corresponding climate variables of 5-year moving averages of the growing season total precipitation and average temperature. We also create climate variability measures in terms of coefficients of variation for the growing season total precipitation and average temperature. Panel C in Table 1 reports summary statistics on these climate variables.

4. Estimation results and robustness checks

We estimate equation (1) and present the coefficient estimates in Table 2. Column (1) in Table 2 presents the effects of climate and other covariates on the amount of leased acreage for dryland wheat farms. Columns (2) - (3) in Table 2 present their effects on leased acreage under cash rent and crop share leases. Table A1 in the Appendix contains the marginal effects of climate variables from Table 2.

Estimation results

Column (1) in Table 2 shows a significant non-linear effect of precipitation on leased acreage for dryland wheat farms. Increases in precipitation lead to reduced leasing land in dry (or low precipitation) areas but increases it in wet (or high precipitation) areas. This can be explained by the fact that rising precipitation in dry areas increases soil moisture and thus improves crop productivity, which leads to a reduction in yield risk and moisture deficit, inducing a shift from fallow systems to transitional and annual cropping systems (Antle et al. 2017; Zhang, Mu and McCarl 2017). In contrast, in wet areas soil moisture deficit is not an issue and thus farmers would increase scale of operation to lower production cost through leasing land.

Temperature also shows a significant non-linear effect on leased acreage for dryland farms. This indicates that higher temperatures over the growing season improve crop productivity below a critical threshold (5.8 °C in this study) and increase it above that (Mendelsohn and Dinar 2003). Since most PNW dryland wheat farm are located in relatively cool and dry climate areas, the marginal effects of precipitation and temperature on leased farmland acreage are both negative as shown in column (1) of Table A1 in the Appendix.

Now we focus on differences in climate impacts on leased farmland acreage between cash rent and crop share leases. We find that precipitation increases have a larger negative effect on the use of crop share leases than it does on cash rent leases. We also find that temperature variability has a significant positive effect on the acreage of crop share leases. An explanation for these results is that crop share leases to a larger extent split return and risk between tenants and landlords, lowering return and risk relative to cash rent leases (Paulson and Schnitkey 2013). In turn when rising precipitation increases crop productivity and economic return, the land leased under crop share leases decreases. Additionally, tenants increase leased crop share acreage to further spread risk to landlords when there are increases in temperature variability and associated yield risk. In contrast, temperature variability has an insignificant effect on the extent of cash rent leases, reflecting that tenants with cash rent leases pay a fixed amount of rent for leasing land and assume all production risk.

Robustness Checks

We conduct two robustness checks that involve the use of a subset of the sample and an alternative construction of the climate variables. We first consider that farmers under a production contract may behave differently on leasing decisions compared to those without a production contract.[1] We re-estimate the model excluding dryland wheat farms with a production contract. The estimated coefficients of climate variables on leased farmland acreage are largely unchanged (in Table 3). This result is expected because of a small number of PNW dryland wheat farms under a production contract (about 9% in the sample).

[1] A production contract is an agreement setting terms, conditions, and fees to be paid by the contractor to the farm operation.

Second, we use alternative climate variables in equation (1), employing 22-year moving averages of growing season total precipitation and temperature. Results in Table 3 show that there are no meaningful changes in the estimates of the climate variables on the extent of leased farmland acreage.

5. Land leasing implications of the projected climate change

In this section, we simulate the effect of projected climate change for 2050 on leased acreage using projections from 20 of the Coupled Model Intercomparison Project Phase 5 (CMIP5) models as downscaled by Abatzoglou (2011)[2]. In doing this, we evaluate the regression equation presented in Column (1) of Table 2 for all land leasing. The CMIP5 projections are those arising under IPCC Representative Concentration Pathways (RCPs) 4.5 and 8.5, which represent medium and high atmospheric greenhouse gas emission levels.

Figure 1 summarizes the CMIP5 projected climate changes for the PNW region using the difference between 2020 to 2049 and 1982 to 2011averaged across the 20 global climate models. Temperatures are projected to increase by +1.2°C under RCP 4.5 and +1.5°C under RCP 8.5. Most of the climate models project precipitation increases with a multi-model mean increase of +16 mm under RCP 4.5 and +14 mm under RCP 8.5.

Figure 2 presents the 2050 leased acreage results in terms of the mean and a 95% confidence interval. The ensemble projection shows that leasing will become less common, on average decreasing by 23% and 29% under RCPs 4.5 and 8.5, respectively. Also shown in Figure 2, there is a wide band of results across the global climate model projections due to future climate uncertainty.

[2] The specific global climate models included in this paper are: (1) CCSM4, (2) CSIRO-Mk3-6-0, (3) inmcm4, (4) IPSL-CM5A-LR, (5) IPSL-CM5A-MR, (6) IPSL-CM5B-LR, (7) MRI-CGCM3, (8) NorESM1-M, (9) bcc-csm1-1, (10) bcc-csm1-1-m, (11) BNU-ESM, (12) CanESM2, (13) CNRM-CM5, (14) GFDL-ESM2G, (15) GFDL-ESM2M, (16) HadGEM2-CC365, (17) HadGEM2-ES365, (18) MIROC5, (19) MIRC-ESM, (20) MIROC-ESM-CHEM. For more on these climate models, see Flato et al.(2013) in the latest IPCC report.

In Figure 3, we show the spatial distribution of changes in leased acreage from 2012 to 2050. There we find broad spatial heterogeneity in leased acreage changes with the largest increase in the Inland Pacific Northwest.

6. Conclusions

In this paper, we investigate the relationship between climate and farmland leasing for PNW dryland wheat farms and then project changes in leased acreage under projected future climate. Our results show that a projected warmer and wetter climate reduces the extent of leasing, suggesting that leasing land is a potential climate change adaptation strategy. Our projection is that by 2050, leased acreage on average will decline by 23% and 29% relative to 2012 levels under RCPs 4.5 and 8.5. Our findings on reduced leasing imply that future climate will further consolidate the agricultural industry as larger farms own more land.

There are several shortcomings and possible extensions to this work. First, we only consider farms that lease land from others, not those that lease land to others. With a changing climate, there may be changes in the rate at which farmers exit the agricultural sector and in turn lease their land to others. Second, we do not consider converting land to grazing or non-agricultural use which Mu, McCarl and Wein (2013) and Mu et al. (2017) show is an observed adaptation strategy. Third, the available data only provide information on farm operators not agricultural landlords. Estimating a parallel model of landlord actions would be another area for future research. Fourth, our predictions on leased farmland acreage are based on current socio-economic and non-climate biophysical conditions. Future research needs to design scenarios with altered socio-economic conditions, technologies, and policies (Antle et al. 2017). Fifth, we do not consider dryland farms shifting to irrigated farms. Last, our model does not capture CO_2 fertilization effects which Attavanich and McCarl (2014) show affects wheat yields.

Conflicts of Interest:

The authors declare no conflict of interest.

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Table 1: Summary statistics of dryland wheat farms in the U.S. Pacific Northwest region

	2002		2007		2012		
	Mean	Std. dev.	Mean	Std. dev.	Mean	Std. dev.	Variable Description
Panel A							
Land leased	0.72	1.71	0.77	1.70	0.81	1.76	Leased farmland acreage (acre)
CRP and WRP programs	0.04	0.25	0.03	0.11	0.02	0.09	Share of cropland under CRP and WRP programs
Classified as large farm	0.60	0.49	0.69	0.46	0.72	0.45	Total farm revenue of over $250,000 (1 = yes, 0 = no)
Farming experience	23.91	12.44	26.39	13.03	26.77	13.88	Farming experience (years)
Farming occupation	0.94	0.24	0.90	0.30	0.91	0.28	Operator occupation (1 = farming, 0 = employed off-farm)
Panel B							
Slope	9.74	7.16	10.05	7.22	10.45	7.50	Average land slope in percent
Soil organic content	5.48	2.84	5.40	2.58	5.61	2.97	Soil organic content in one meter depth (kg C/m^2)
Sand content	32.17	12.36	31.86	11.82	31.93	11.97	Percent of particles with 0.05-2 mm in diameter
Clay content	13.46	4.91	13.48	4.66	13.73	4.95	Percent of particles with < 2 mm in diameter
Soil loss tolerance (T) factor	3.44	0.69	3.43	0.70	3.42	0.71	Soil loss tolerance factor (tons/acre/year)
Panel C							
Precipitation	12.15	7.26	11.20	5.19	12.03	7.05	5-year average of growing season total precipitation (inch)
Average Temperature	7.07	1.82	7.01	1.94	6.43	1.89	5-year average of growing season average temperature (℃)
CV Precipitation	3.87	0.64	3.84	0.75	4.02	0.71	Coefficient of variation of total precipitation
CV Ave. Temperature	8.01	2.85	8.21	2.62	9.58	3.16	Coefficient of variation of average temperature
N	2850		2432		2407		

Notes: All climate variables are computed over the growing season from September to June (inclusive).

Table 2: Coefficient estimates for impact of climate and other factors on PNW dryland wheat leased acreage across leasing forms

Variables	(1) All farms	(2) Farms using cash rent leases	(3) Farms using crop share leases
Precipitation	-0.0635***	-0.0617***	-0.0773***
	(0.0144)	(0.0162)	(0.0166)
Precipitation squared	0.0006***	0.0005**	0.0007***
	(0.0002)	(0.0002)	(0.0002)
Temperature	0.4984***	0.5411***	0.4705***
	(0.1220)	(0.1390)	(0.1364)
Temperature squared	-0.0428***	-0.0460***	-0.0476***
	(0.0096)	(0.0112)	(0.0108)
CV precipitation	-0.0901*	-0.0973	-0.0967
	(0.0535)	(0.0605)	(0.0600)
CV temperature	0.0702	0.0699	0.1339**
	(0.0535)	(0.0579)	(0.0654)
CRP and WRP programs	0.0892	0.1050	0.1318
	(0.0755)	(0.1238)	(0.0951)
Classified as large farm	1.5326***	1.4372***	1.5619***
	(0.0691)	(0.0752)	(0.0737)
Farming experience	-0.0086***	-0.0074***	-0.0086***
	(0.0015)	(0.0019)	(0.0018)
Farming occupation	0.3993***	0.4017***	0.3931***
	(0.0484)	(0.0650)	(0.0583)
Slope	0.0026	0.0035	0.0025
	(0.0048)	(0.0059)	(0.0052)
Soil organic content	-0.0223	-0.0202	-0.0238
	(0.0142)	(0.0168)	(0.0149)
Sand content	-0.0026	-0.0023	-0.0079
	(0.0062)	(0.0072)	(0.0054)
Clay content	-0.0139	-0.0091	-0.0198*
	(0.0100)	(0.0107)	(0.0117)
Soil loss tolerance (T) factor	-0.0780	-0.1032	-0.0715
	(0.0768)	(0.0847)	(0.0907)
Intercept	Yes	Yes	Yes
State-year fixed effects	Yes	Yes	Yes
R-squared	0.187	0.166	0.200
Observations	10,135	7,057	7,409

Notes: Climate variables used are 5-year moving averages of growing season total precipitation and average temperature and their square terms as well as the moving 22-year coefficients of variation of growing season total precipitation and average temperature. Standard errors are in parentheses. Statistical significance is marked with *** p<0.01, ** p<0.05, * p<0.1

Table 3: Coefficient estimates for leased dryland farmland acreage for robustness checks

Variables	(1) Farms without a production contract	(2) 22-year averages for climate variables
Precipitation	-0.068***	-0.066***
	(0.014)	(0.015)
Precipitation squared	0.001***	0.001***
	(0.000)	(0.000)
Temperature	0.511***	0.482***
	(0.118)	(0.125)
Temperature squared	-0.041***	-0.041***
	(0.009)	(0.010)
CV precipitation	-0.085*	-0.087
	(0.049)	(0.054)
CV temperature	0.068	0.064
	(0.050)	(0.056)
Intercept	Yes	Yes
Soil variables	Yes	Yes
Socio-economic variables	Yes	Yes
State-year fixed effects	Yes	Yes
R-squared	0.216	0.186
Observations	9,043	10,135

Notes: Climate variables used in (1) are 5-year moving averages of growing season total precipitation and average temperature and their square terms as well as the moving 22-year coefficients of variation of growing season total precipitation and average temperature. Climate variables used in (2) are 22-year moving averages of growing season total precipitation and average temperature and their squared terms as well as the same coefficients of variation in (1). Soil variables used include slope, amount of soil organic matter, sand and clay contents, and soil loss tolerance factor. Socio-economic variables include share of cropland under CRP and WRP programs, farm revenue size, farming experience and occupation. Standard errors are in parentheses. Statistical significance is marked with *** p<0.01, ** p<0.05, * p<0.1

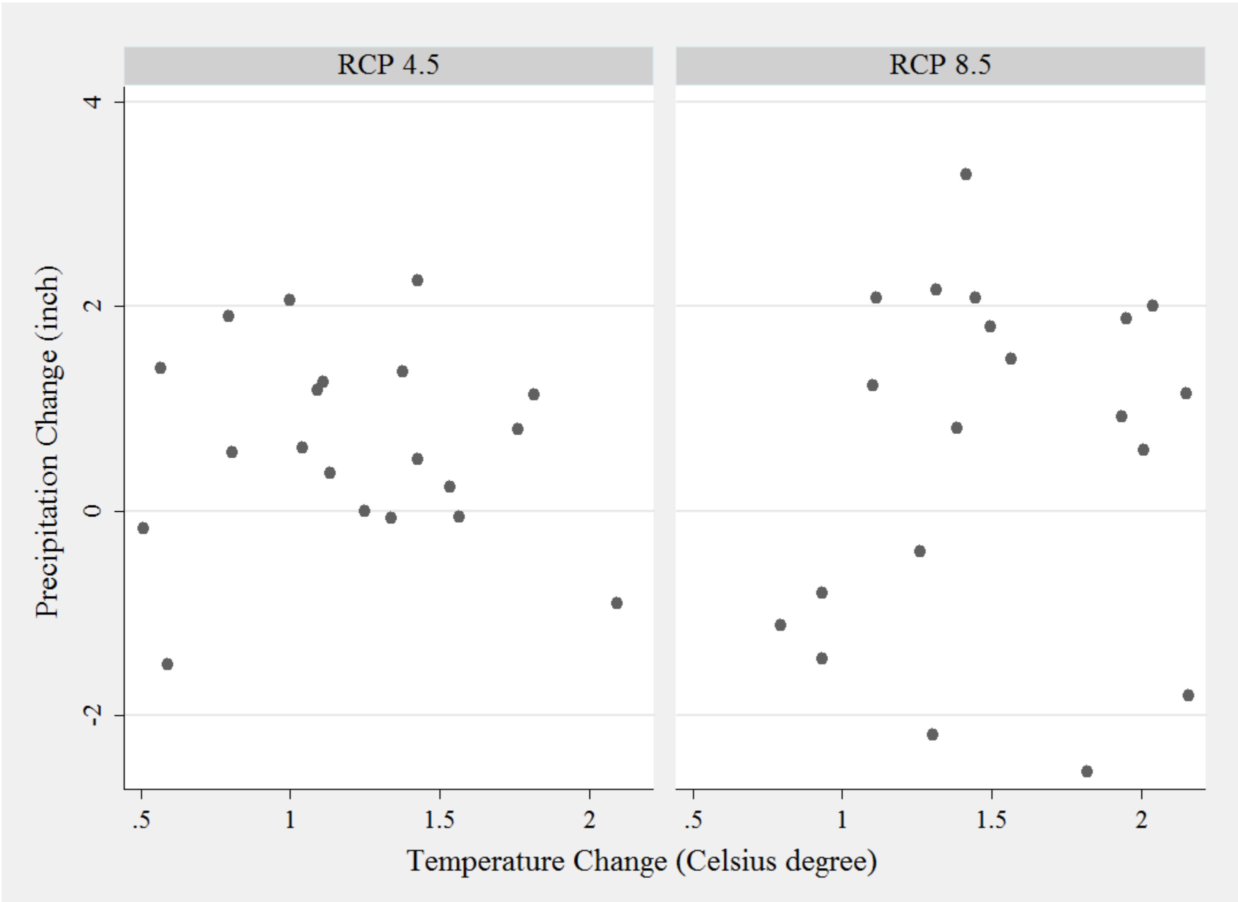

Figure 1: Multi-model projected changes in 30-year averages of growing season total precipitation and average temperature for 2020-2049 relative to 1982-2011. Each dot represents a projection from a particular CMIP5 global climate model.

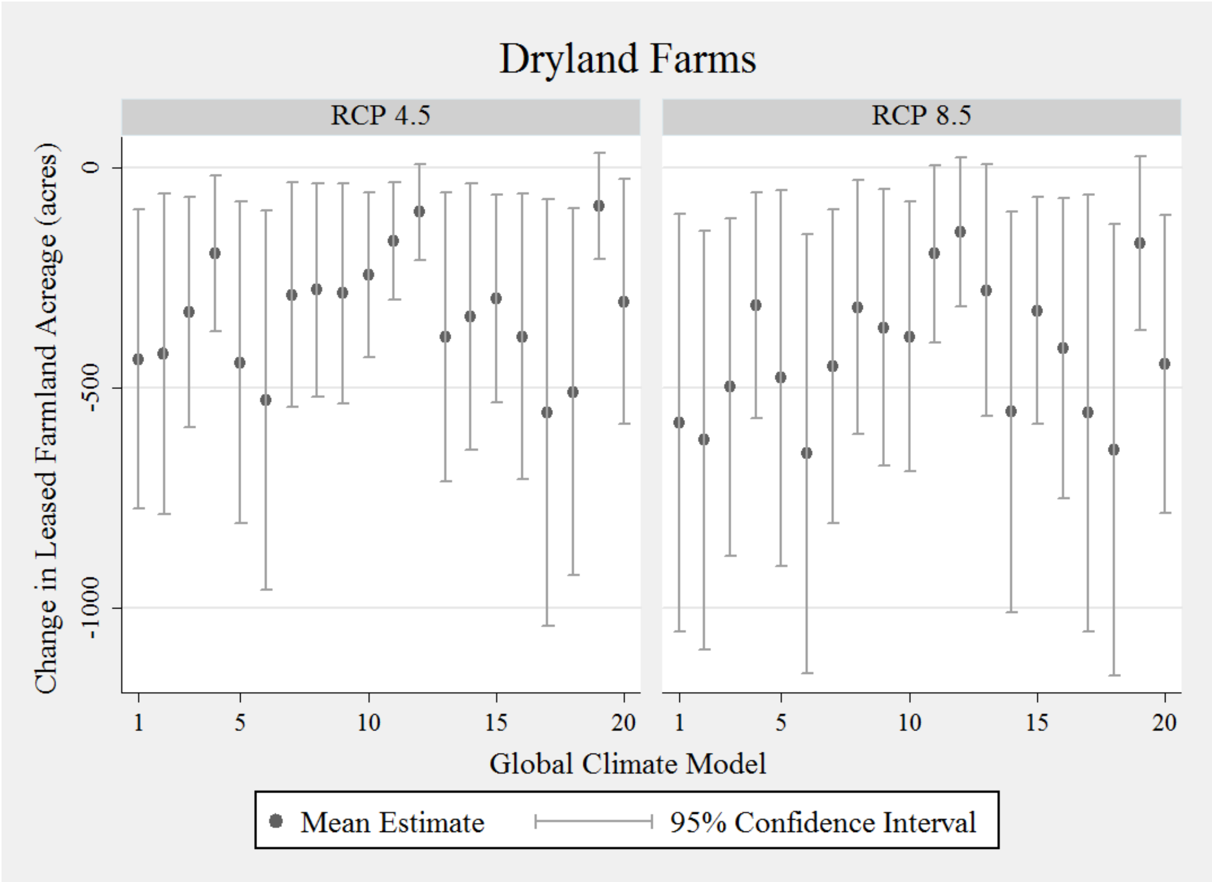

Figure 2: Projected average changes in leased farmland acreage for PNW dryland wheat farms under RCPs 4.5 and 8.5 from 2012 to 2050 (Unit: acre)

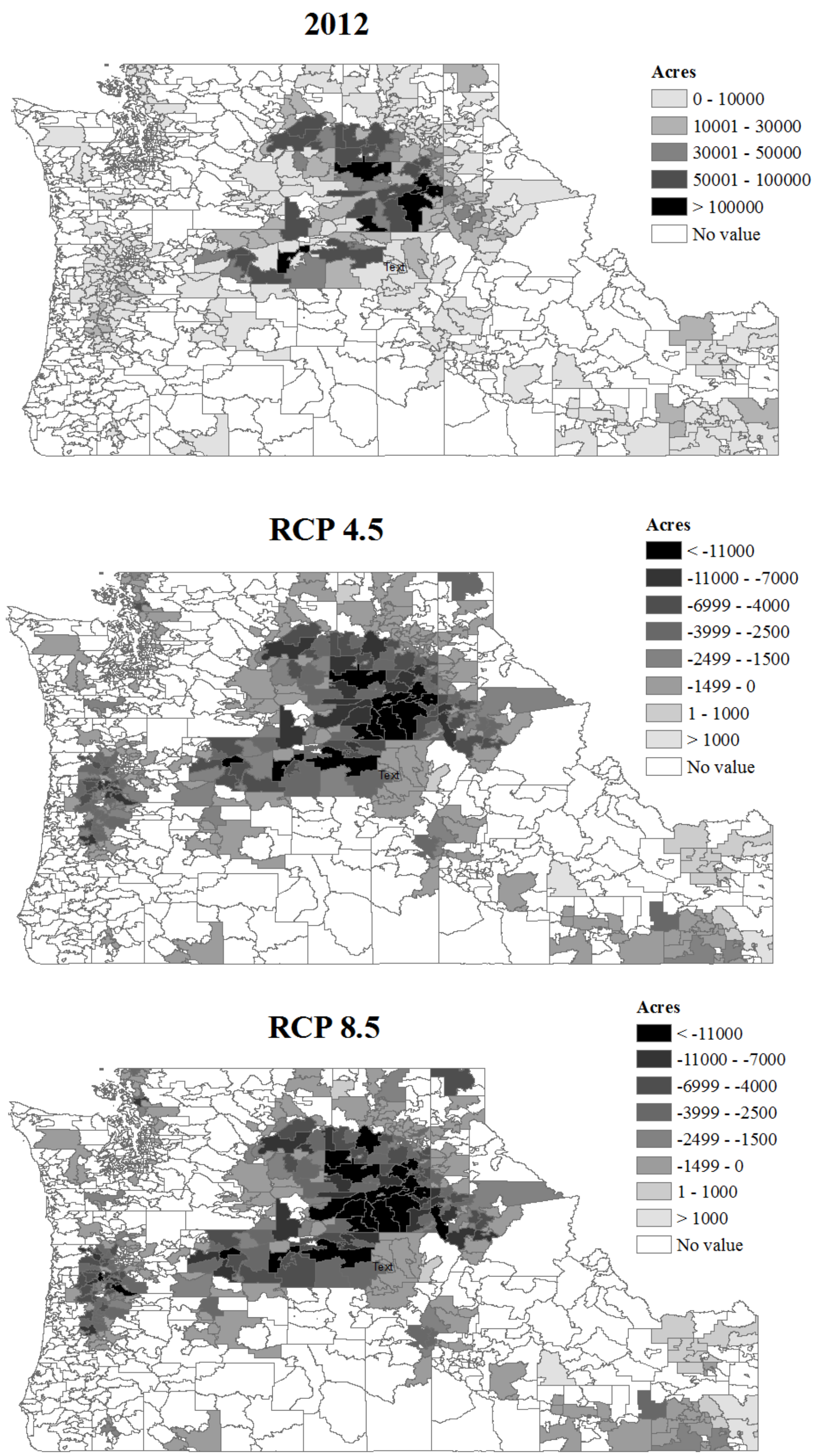

Figure 3: Observed 2012 leased farmland acreage for PNW dryland wheat farms and changes in leased acreage from 2012 to 2050 under RCPs 4.5 and 8.5 by ZIP code

Appendix:

Table A1: Estimated marginal effects on leased farmland acreage for dryland wheat farms at the sample mean

Variables	(1) All farms	(2) Farms using cash rent leases	(3) Farms using crop share leases
Precipitation	-0.0414***	-0.0410***	-0.0527***
	(0.0083)	(0.0088)	(0.0097)
Temperature	-0.1238	-0.1271	-0.2179*
	(0.0973)	(0.1083)	(0.1185)
CV precipitation	-0.0901*	-0.0973	-0.0967
	(0.0535)	(0.0605)	(0.0600)
CV temperature	0.0702	0.0699	0.1339**
	(0.0535)	(0.0579)	(0.0654)
Intercept	Yes	Yes	Yes
Soil variables	Yes	Yes	Yes
Socio-economic variables	Yes	Yes	Yes
State-year fixed effects	Yes	Yes	Yes
R-squared	0.187	0.166	0.200
Observations	10,135	7,057	7,409

Notes: Climate variables used are 5-year moving averages of growing season total precipitation and average temperature and their square terms as well as the moving 22-year coefficients of variation. Soil variables used include slope, amount of soil organic matter, sand and clay contents, and soil loss tolerance factor. Socio-economic variables include share of cropland under CRP and WRP programs, farm revenue size, farming experience and occupation. Standard errors are in parentheses. Statistical significance is marked with *** $p<0.01$, ** $p<0.05$, * $p<0.1$