The Impacts of Climate Change on U.S. Agriculture - Benefits from Crop Adaptation

Chenguang Wang, Soren Anderson, and Jinhua Zhao

Michigan State University

August 4-6, 2013

Camp Resources XX Workshop

Introduction

- Climate (temperature, rainfall): direct and major inputs in agriculture.
- Climate change: higher temperature and undetermined rainfall, shuffle the relative profitability of agricultural activities and land use choice.
- Will farmers recognize climate change and its impact on their land? If so, will they adapt and how?
- What are the impacts on U.S. agriculture from future climate change? Beneficial or not? Homogeneous or heterogeneous?

Research Questions & Findings

Research Questions

1. What are the values of potential adaptation strategies?
2. Which adaptation strategy should farmer take at different location?
3. What are the impacts of climate change on U.S. agriculture?

Preliminary Findings

1. Increase in temperature and rainfall are beneficial to U.S. agriculture in the past (average effect).
2. Growing heat tolerant crops and drought tolerant crops in extremely hot area increase agricultural land value (heterogeneous effect).

Contributions

Intellectual merits

1. Estimate the heterogeneous impact of climate change on agriculture.
2. Quantify values of adaptation strategies.
3. Re-estimate the impacts on agricultural land value of climate change using different adaptation strategies.

Broad impacts

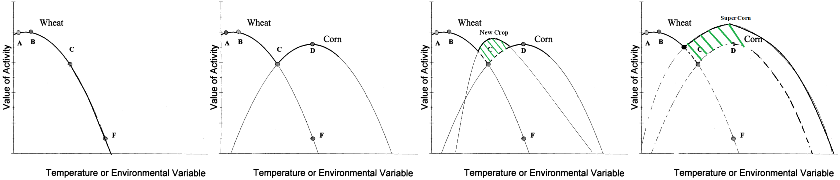
Provide guidance to 1) government and private investors to engage in R&D for new crops, technology, and practice; 2) university extensions to present and communicate with farmers about adaptation strategies; and 3) directly help farmers to make land use and adaptation adoption decision to minimize potential loss caused by climate change.

Impacts of Climate Change and Adaptation

- Production Function: Adams (1989).
- Natural Experiment: Taraz (2012) - irrigation technology and crop choice by Indian Monsoon, Hornbeck and Keskin (2011) - land value and crop choice by Ogallala.
- Econometrics: Schlenkder and Roberts (2009) and Burke and Emerick (2012) on crop yields.

Ricardian Approach

- Ricardian Approach: Mendelsohn, Nordhause, and Shaw (1994) - land value.
- Assume full adaptation, e.g., land use change, introduction of new crops, and technological change.



- But it doesn' infer the value of each adaptation strategy and make recommendation of adaptation choice.
- Oh, wait, I find something in common: CROP ATTRIBUTES.

Evolution of the Ricardian Approach on Land Valuation

Mean value function in Mendelsohn, Nordhaus, and Shaw (1994) :

$$\bar{V}_i = \beta z_i \tag{1}$$

1. Omitted Variable Bias: Schlenker, Hanemann, and Fisher (2005, 2006), Deschênes and Greenstone (2007, 2012), Massetti and Mendelsohn (2012)

$$\bar{V}_i = \beta z_i + \delta_i \tag{2}$$

2. Selection Bias: Timmins (2006)

$$\bar{V}_i = \beta_j z_i - \left(\frac{1}{\alpha} lns_{ij}\right) \tag{3}$$

3. Random Coefficient:

$$\bar{V}_i = \bar{\beta}_i z_i - \left(\frac{1}{\alpha} ln\bar{s}_i\right) \tag{4}$$

Empirical Model: Crop Adaptation

Based on Timmins (2006):

$$\bar{V}_i = \beta_j z_i - \left(\frac{1}{\alpha} lns_{ij}\right) \quad (5)$$

I introduce crop adaptation by specifying the beta coefficients following Anderson, Wang, and Zhao (2012):

$$\beta_j = \alpha_o + \sum_{a \in A} \alpha_a w_{aj} \quad (6)$$

Model:

$$\bar{V}_i = \alpha_o z_i + \sum_{a \in A} \alpha_a w_{aj} z_i + \delta_i - \left(\frac{1}{\alpha} lns_{ij}\right) + \varsigma_j + \upsilon_{ij} \quad (7)$$

Estimation: Long-Differences

$$\ddot{\bar{V}}_i = \alpha_o \ddot{z}_i + \sum_{a \in A} \alpha_a w_{aj} \ddot{z}_i + \gamma \ddot{L}_{ij} \quad (8)$$

where $\gamma = -\frac{1}{\alpha}$ and $\ddot{L}_{ij}$ measures land use choice change.

- $\alpha_o, \alpha_a, \gamma$ are to be estimated by OLS.
- Unobserved crop heterogeneity, unobserved county heterogeneity, and the crop-county residual can be approximated by:

$$\sum_i \sum_t \left[\bar{V}_{it} - \hat{\alpha}_o z_{it} - \sum_{a \in A} \hat{\alpha}_a w_{aj} z_{it} - \hat{\gamma} L_{ijt} \right] = \hat{\varsigma}_j \quad (9)$$

$$\sum_j \sum_t \left[\bar{V}_{it} - \hat{\alpha}_o z_{it} - \sum_{a \in A} \hat{\alpha}_a w_{aj} z_{it} - \hat{\gamma} L_{ijt} \right] = \hat{\delta}_i \quad (10)$$

$$\bar{V}_{it} - \hat{\alpha}_o z_{it} - \sum_{a \in A} \hat{\alpha}_a w_{aj} z_{it} - \hat{\gamma} L_{ijt} - \hat{\delta}_i - \hat{\varsigma}_j = \hat{\upsilon}_{ij} \quad (11)$$

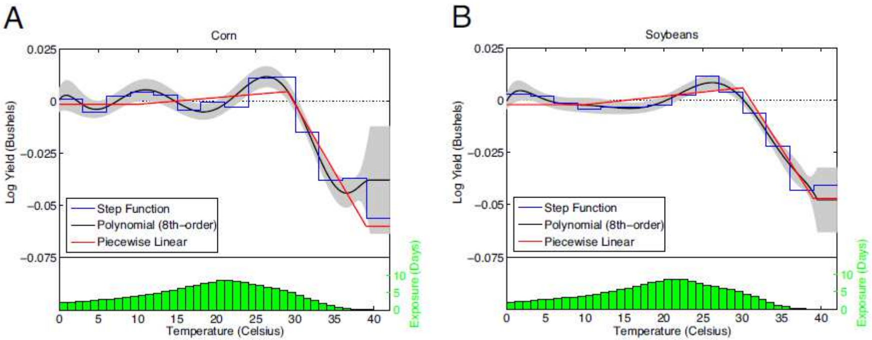
Data: county level

- Farmland value and crop acreage: Census of Agriculture 1978-1982 (before), 1997-2002 (after).
- Climate Characteristics: 1950-1980 (before) and 1970-2000 (after) temperature and rainfall from PRISM via Schlenker and Roberts (2009) and day length from Albouy, Graf, Kellogg, and Wolff (2013).
- Crop attributes: USDA Plant Characteristics Database and crop science research via Anderson, Wang, and Zhao (2012).

Table 1: Crop Attributes

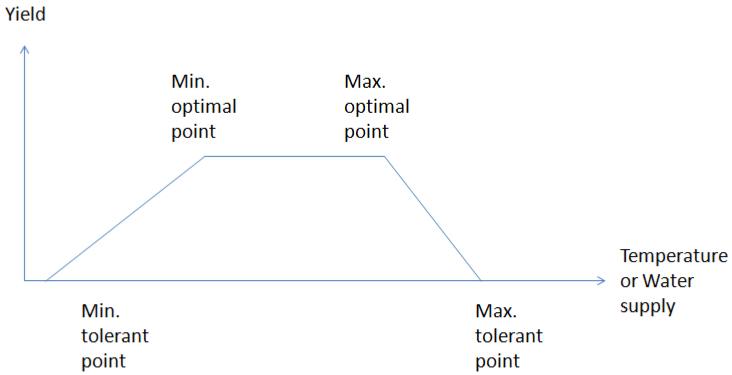
Crop	Photoperiod	Photosynthesis	Height (ft)	RUE	Minimum Temperature	Minimum Frost Free Days	Minimum Water Need	Maximum Water Need	Sensitivity to Drought	Drought Tolerance	Root (inches)
Barley	long	c3	2.5	1.6	-43	90	450	650	low	Medium	10
Buckwheat	long	c3	2	1.65	40	365				Low	12
Corn	neutral	c4	8	2	32	90	500	800	medium	Low	8
Cowpea	short	c3	2.5	1.09	47	120				None	6
Oats	long	c3	2	1.45	-23	90	450	650	low	Low	8
Wildrice	short	c3	9.8	1.7	32	95	450	700	high	None	6
Rice	short	c3	2	1.7	37	150	450	700	high	Low	6
Rye	long	c3	3.5	2	-33	110				Medium	8
Millet	short	c3	3	1.9	47	120	450	650	low	Low	10
Sorghum	short	c4	4	1.75	47	90	450	650	low	High	12
Soybeans	short	c3	3	1	-28	140	450	700	low	Medium	8
Wheat	long	c3	3.3	1.65	-28	100	450	650		Medium	18
Alfalfa	long	c3	2	1.1	-43	90	800	1600	low	High	24
Cotton	short	c3	6	1.5	50	365	700	1300	low	High	16
Apple		c3	30		-78	100				Medium	30
OrangeSweet		c3	30		17	365				Medium	60
Sugarcane	short	c4	12	1.75	17	365	1500	2500	high	High	24
Buckbean	neutral	c3	0.8	1.45	-33	100	300	500	medium	None	10
Hyacinthbean	neutral	c3	4	1.45	31	300	300	500	medium	High	12
Mescalbean	neutral	c3	15	1.45	7	200	300	500	medium	Medium	24
Sacbean	neutral	c3	20	1.45	40	365	300	500	medium		36
Beans	neutral	c3	3	1.45	47	120	300	500	medium	None	6
Bushbean	neutral	c3	4	1.45	23	365	300	500	medium	Medium	24
Chickpea	long	c3	3	0.67	-43	115	350	500	medium	Medium	16
Canola	long	c3	4	1.4	17	130				Low	6
Flaxseed	short	c3	2.6	1.7	-43	100				Low	2
Mustard	long	c3	3	1.92	-13	125				Low	12
Peanuts	short	c3	1.3	1.2	12	265	500	700	low	High	20
Sunflower	neutral	c3	9	1.85	52	80	600	1000	low	Medium	8
Tomatoes	neutral	c3	6	1.05	32	365	400	800	medium	Low	24
Switchgrass	short	c4	5	2.2	-43	120				Medium	12
Miscanthus	short	c4	5	2	-18	120				Medium	14
Timothy	long	c3	3	1.2	-43	90				Low	10
Potatoes	long	c3	2	1.65	45	110	500	700	high	High	12
Safflower	long	c3	3	1.45	20	120				High	10
Sugarbeets	long	c3	2	1.9	34	120	550	750	low	Low	5
Tobacco	short	c3	6	1.52	65	120				Medium	24

Figure 1: Crop Yield and Temperature

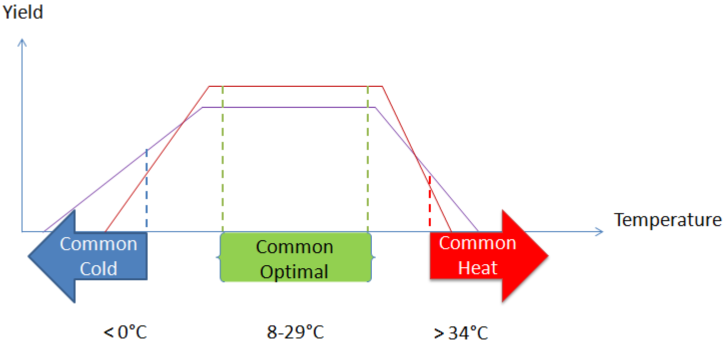


Source: Schlenker and Roberts (2009)

Climate Variables: 3-stage



Climate Variables: 3-stage



- Temperature: Freezing Degree Days, Average Optimal Degree Days, and Heating Degree Days.
- Rainfall: Insufficient Rainfall, Average Optimal Rainfall, and Excessive Rainfall.

Table 2: Descriptive Statisitcs of Long Differences Dataset (1980-2000)

Land Value (2002 dollars)	1.282	Freezing Degree Days × Minimum Tolerant Temperature	-0.236
	(1.366)		(1.261)
Freezing Degree Days (°C)	0.0271	Heating Degree Days × RUE	-0.0164
	(0.0233)		(0.0284)
Average Optimal Degree Days (°C)	0.0463	Heating Degree Days × Low Drought Tolerance	-0.00327
	(0.127)		(0.0110)
Heating Degree Days (°C)	-0.0111	Insufficient Rainfall × Minimum Water Need	-1.067
	(0.0185)		(0.898)
Insufficient Rainfall (cm)	-0.00204	Insufficient Rainfall × High Drought Tolerance	-0.000625
	(0.00157)		(0.00128)
Average Optimal Rainfall (cm)	0.00303	Excessive Rainfall × Maximum Water Need	4.537
	(0.00409)		(6.329)
Excessive Rainfall (cm)	0.00520	Excessive Rainfall × Root Depth	0.0730
	(0.00642)		(0.105)
Average Optimal Degree Days × Growing Season Length	5.780	ln(Crop Share)	-0.383
	(18.69)		(1.207)
Observations	14,563		

Table 3: Long Differences Estimates of the Impacts of Climate Change on Agricultural Land Value (1980-2000)

Independent Variable	Coefficients	Independent Variable	Coefficients
Freezing Degree Days (°C)	-20,922***	Heating Degree Days × RUE	2,874***
	(1,214)		(760.8)
Average Optimal Degree Days (°C)	1,647***	Heating Degree Days × Low Drought Tolerance	-3,222***
	(286.1)		(553.8)
Heating Degree Days (°C)	13,198***	Insufficient Rainfall × Minimum Water Need	46.55*
	(1,766)		(24.93)
Insufficient Rainfall (cm)	-54,583*	Insufficient Rainfall × High Drought Tolerance	14,206*
	(32,248)		(7,572)
Average Optimal Rainfall (cm)	5,157	Excessive Rainfall × Maximum Water Need	-6.453**
	(11,167)		(2.655)
Excessive Rainfall (cm)	9,223**	Excessive Rainfall × Root Depth	1,320***
	(4,564)		(192.2)
Average Optimal Degree Days × Growing Season Length	6.777***	ln(Crop Share)	-47.67***
	(1.642)		(9.049)
Freezing Degree Days × Minimum Tolerant Temperature	-13.45***	Constant	1,710***
	(4.145)		(53.48)
Observations	14,563	R-squared	0.194

Notes: Robust standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1

- Increase in rainfall and temperature can be beneficial to U.S. agriculture and growing heat and drought tolerant crops reinforces the impacts.

Robustness

1. Different cutoffs for temperature (0C,30C) and rainfall (.15mm, .93mm).
2. Farmland value*Interest rate -> land rent as dependent variable, land bubble in 1980s.
3. Panel data approach (short-run adaptation).
4. Cross-sectional approach (long-run adaptation).

Irrigation: east U.S., irrigation cutoff 10%. [not because of irrigation, because of irrigation at very low cost]

Others: urban, population, highway networks

Simulation under Climate Change

1. No crop adaptation (base).
2. Change land use w/o changing crop choice set.
3. Adopt existing crops at new locations.
4. Modify attributes of existing crops, e.g., drought-resistent corn and soybeans in Midwest.
5. Add new crops into producer's choice set, e.g., miscanthus and switchgrass.
6. Apply "sun-screen" to ALL crops in hot areas.