Risks and Options for Water, Food and Energy: Agriculture and the Importance of Extreme Heat

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Outline

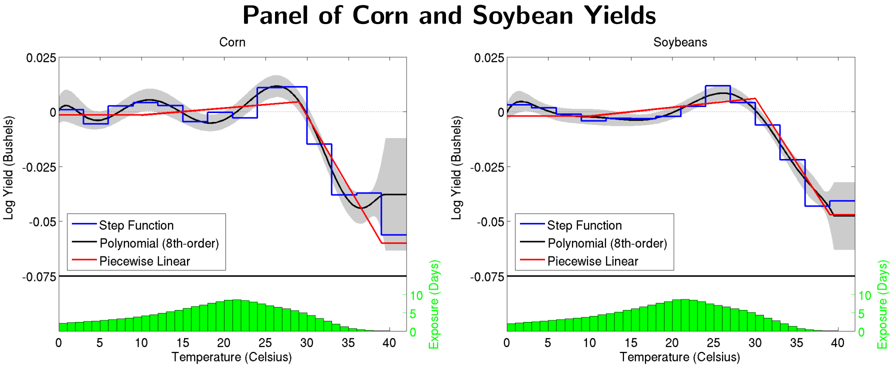
1. Modeling US Yields
2. Water versus Temperature
3. Adaptation to Extreme Heat
4. Adaptation to Production Variability
5. Conclusions

Outline

Link between Weather and US Yields

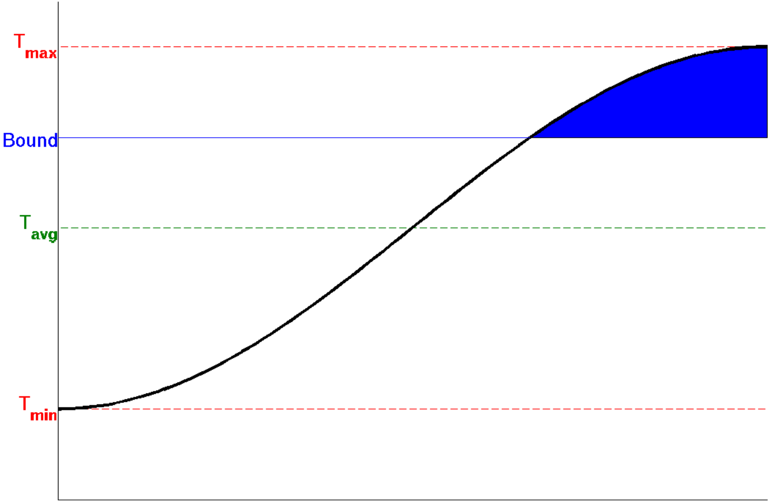
- Four commodity crops account for 75% of calories consumed by humans
  - Maize (corn), wheat, rice and soybeans
  - United States produces 23% of those calories
  - Global market share of US corn $> 40\%$
- Statistical analysis
  - Panel of county-level yields in Eastern United States
  - Corn and Soybeans (two biggest staple commodities in US)
  - Fine-scale weather (daily temperature / precip on 2.5mile grid)
  - Years: 1950-2005
- Model accounts for
  - Amount of time spent in each 1°C interval
  - Quadratic in total precipitation
  - State-specific quadratic time trends
  - County fixed effects

Results: Effect of Temperature on Yields

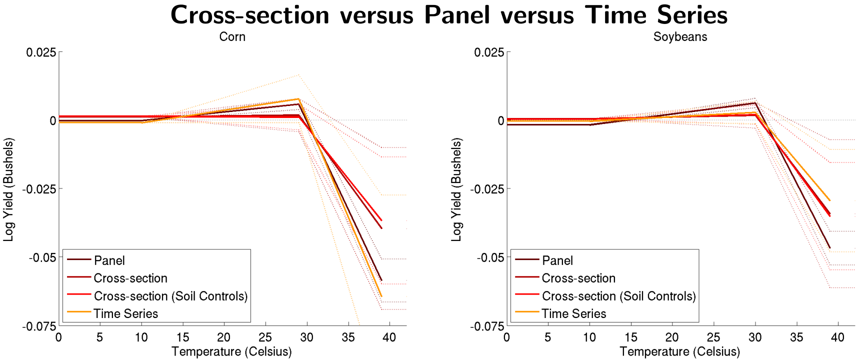


Schlenker & Roberts (PNAS 2009)

Construction of Degree Days

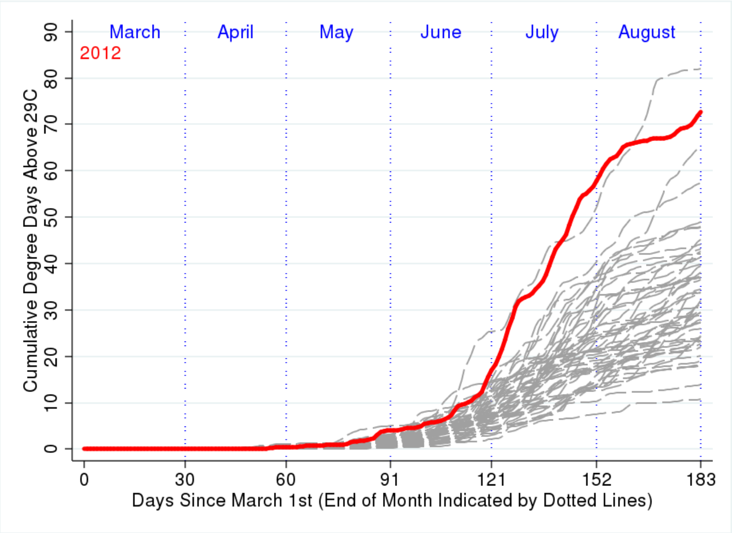


Results for Various Sources of Variation



Schlenker & Roberts (PNAS 2009)

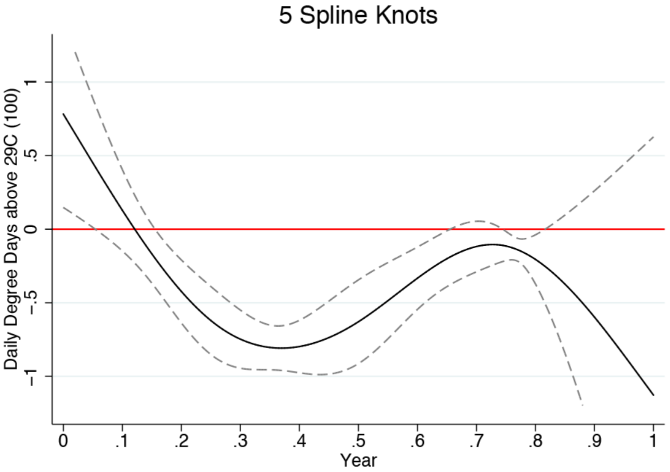
Recent Example: 2012 Heat Wave / Drought



Berry, Roberts & Schlenker (2013)

Recent Example: 2012 Heat Wave / Drought

Coefficient Over Growing Season (0: Planting / 1: Harvest)



Berry, Roberts & Schlenker (2013)

Allowing for Interactions that Can Evolve Over Season

	(1)	(2)	(3)	(4)	(5)	(6)
			Panel A: Time Invariant Variables			
Thousand Degree Days 10-29°C	0.333***	0.354***	0.334***	0.336***	0.313***	
	(0.091)	(0.075)	(0.074)	(0.072)	(0.074)	
Hundred Degree Days Above 29°C	-0.591***	-0.562***				
	(0.086)	(0.107)				
DDays Above 29°C X Precipitation		-32.435	-19.560			
		(31.586)	(25.565)			
Precipitation (m)	0.649***	0.708***	0.650**	0.654**		
	(0.211)	(0.207)	(0.231)	(0.237)		
Precipitation (m) Squared	-0.439**	-0.473***	-0.409**	-0.415**		
	(0.166)	(0.160)	(0.170)	(0.173)		
			Panel B: Joint Significance of Time Varying Variable			
$p_{\text{Degree Days Above 29°C}}$			7.88e-10	4.88e-09	2.22e-07	4.00e-09
$p_{\text{Degree Days Above 29°C X Precipitation}}$				.0000619	.00213	.0157
$p_{\text{Precipitation}}$					.00453	.00426
$p_{\text{Precipitation Squared}}$					.000857	.00186
$p_{\text{Degree Days 10-29°C}}$						.0352
			Panel C: Impact of 2012 Weather Outcome			
Total Production Impact (%)	-18.54	-18.78	-20.79	-20.73	-22.19	-22.80
			Panel D: Prediction Error for 2012			
RMSE - 2012 County Prediction	0.3688	0.3672	0.3329	0.3285	0.3328	0.3271
Pred. Error Total Prod 2012 (%)	8.00	8.09	4.55	4.67	2.96	1.69
R^2	0.5151	0.5167	0.5370	0.5407	0.5524	0.5540
Observations	43249	43249	43249	43249	43249	43249
Counties	1659	1659	1659	1659	1659	1659
Spline Knots (Time Varying Var.)			5	5	5	5

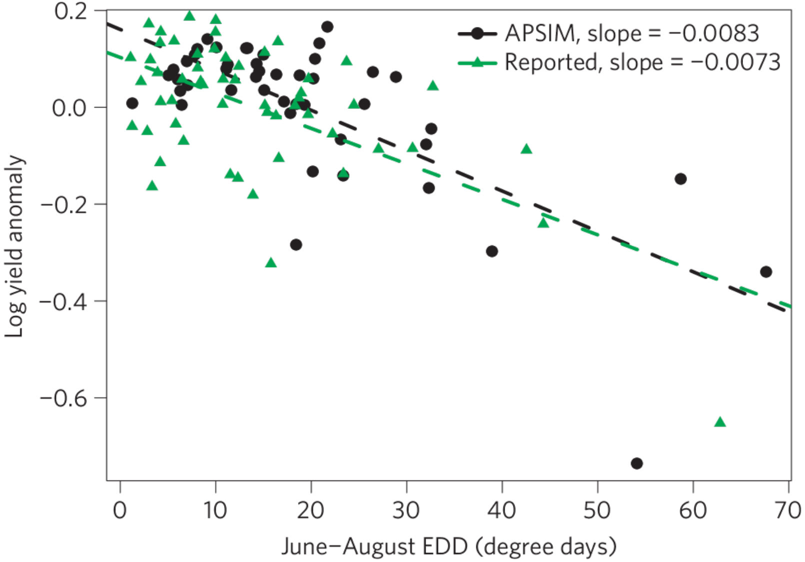
Berry, Roberts & Schlenker (2013)

Outline

Agronomic Evidence on Mechanism

- Biophysical evidence
  - Lobell, Hammer, McLean, Messina, Roberts, Schlenker (2013)
    - APSIM: biophysical model of crop growth
    - Includes water balance, etc
- Mechanism behind EDD (extreme heat)
  - Impacts water stress in two ways
    - Reducing soil water (evaporation)
    - Increased demand for soil water to sustain carbon uptake
  - Precipitation only impacts soil moisture
- Drought is a relative concept
  - Water requirements depend on temperature

Heat versus Water

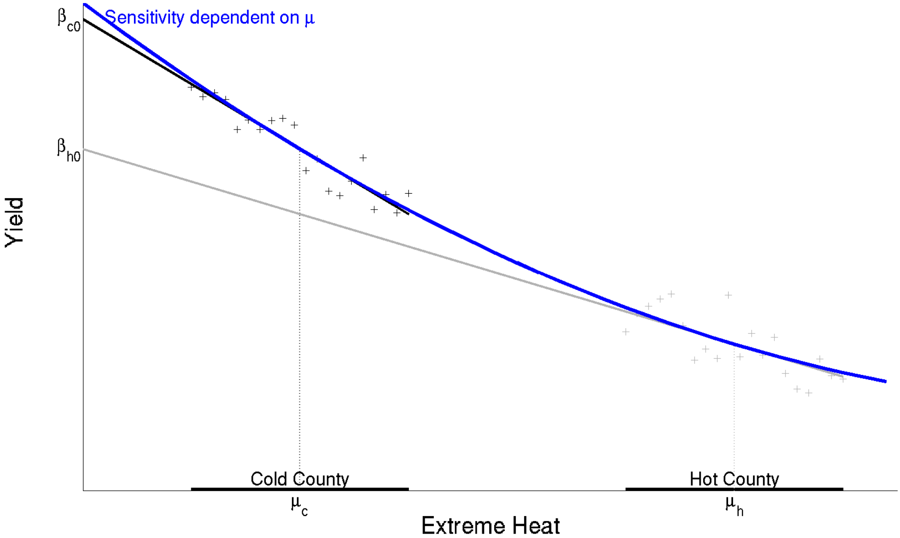


Outline

Adaptation to Extreme Heat

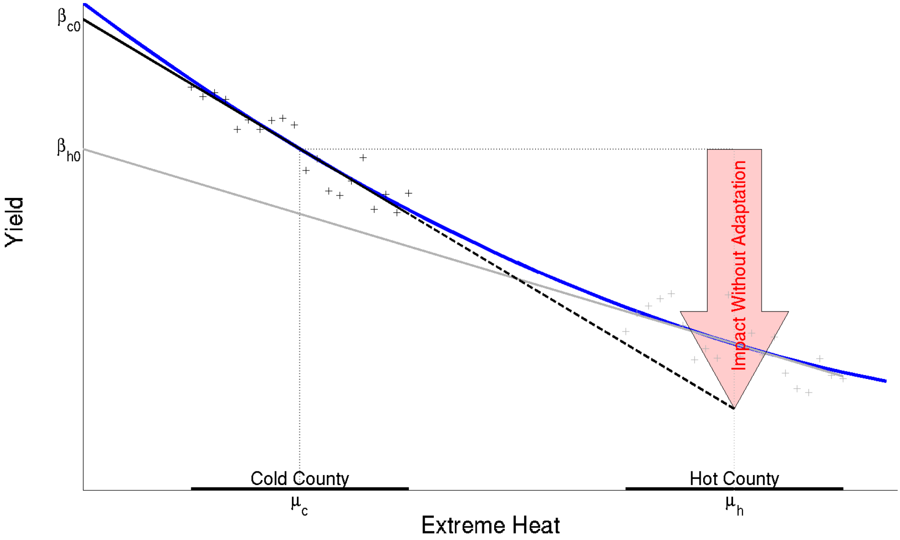
- Tremendous progress in average yields (3-fold increase since 1950)
- No improvement in sensitivity to extreme heat
  - Crops as sensitive in 2010 as in 1950
  - Cross-section gives comparable result to time series
- Possible impediment to adaptation: subsidized crop insurance
  - Farmers don't have full incentive to deal with extreme
  - They will be bailed out to some extend
- Thought experiment (Butler and Huybers, 2013)
  - Are hotter places less sensitive to extreme heat?
  - Can we assume that with climate change places will adapt?
    - Places that are currently cold will reduce sensitivity when they warm
    - But is reduction in sensitivity costless?

Adaption to Extreme Heat: Changing Sensitivity



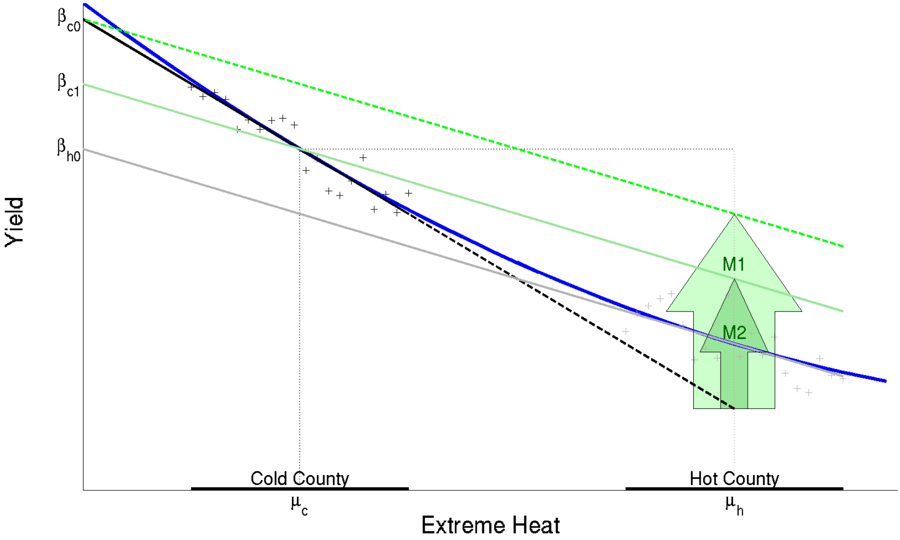
Schlenker, Roberts, and Lobell (2013)

Linear Interpolation: Cold County Becomes Hot



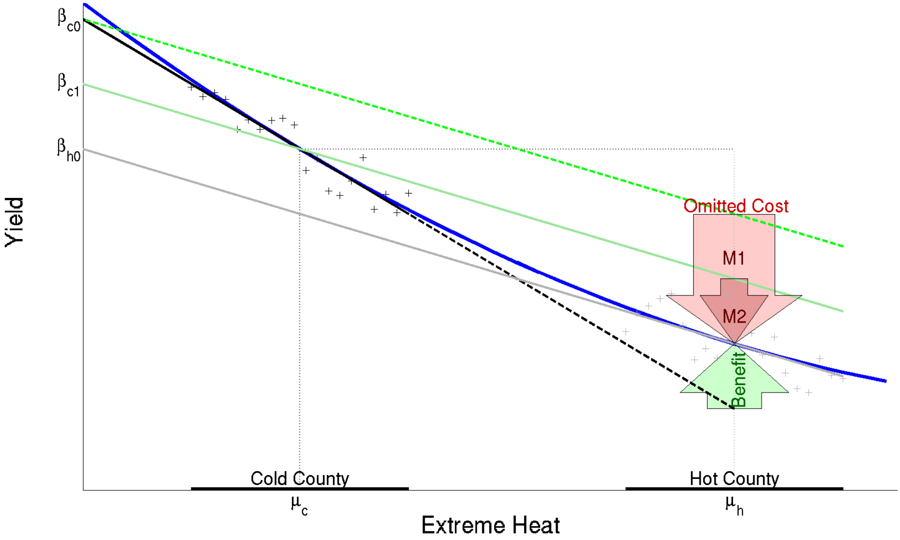
Schlenker, Roberts, and Lobell (2013)

Modeling the Benefit of Adaptation



Schlenker, Roberts, and Lobell (2013)

Benefit and Cost of Adaptation



Schlenker, Roberts, and Lobell (2013)

Impacts of 2°C Warming

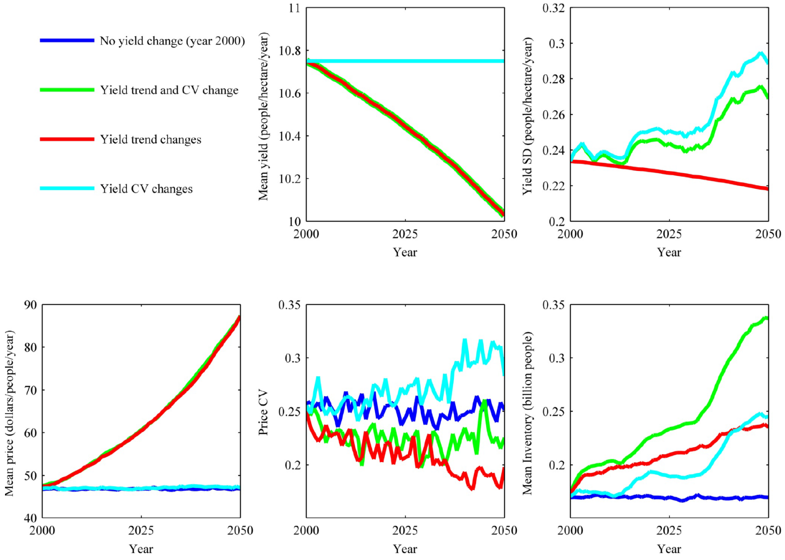
	Impact Among 1829 Counties					Weighted
	Mean	**Min**	**Max**	**Losers**	**Gainers**	**Impact**
	(1a)	**(1b)**	**(1c)**	**(1d)**	**(1e)**	**(2)**
Panel A: Model using Log Yields as Dependent Variable						
Reference Model						
Constant Effect of Heat	-16.5%	-67.6%	14.2%	1610	219	-10.7%
Sensitivity to Heat Varies (Model 2)						
Impact without Adaptation	-17.3%	-38.6%	14.8%	1765	64	-14.9%
Impact with Adaptation	-8.7%	-20.4%	16.1%	1665	164	-7.6%
Robustness vs Average Yield						
Costly Adaptation	-12.5%	-28.8%	15.7%	1717	112	-10.9%
Panel B: Model using Yields as Dependent Variable						
Reference Model						
Constant Effect of Heat	-18.2%	-184.8%	15.9%	1551	278	-7.4%
Sensitivity to Heat Varies (Model 2)						
Impact without Adaptation	-16.0%	-147.7%	16.7%	1773	56	-10.8%
Impact with Adaptation	-3.9%	-35.2%	63.2%	1557	272	-3.7%
Robustness vs Average Yield						
Costly Adaptation	-9.2%	-83.7%	40.7%	1693	136	-6.8%

Outline

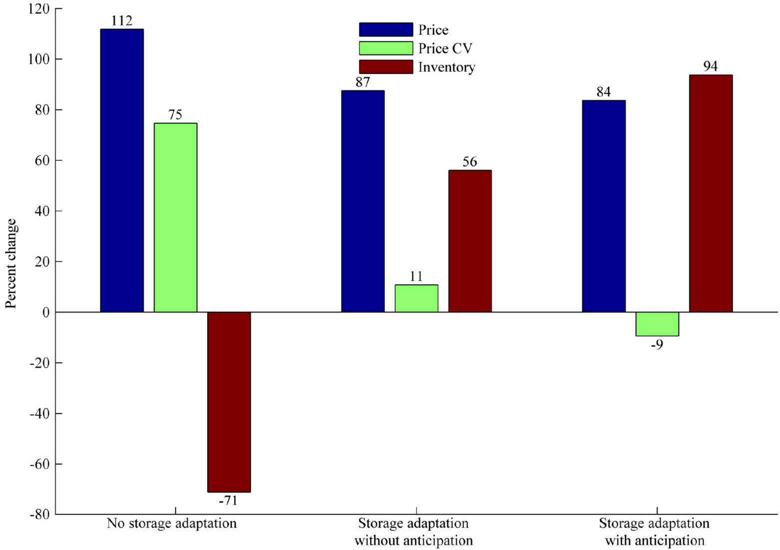
Yield Variability in the Future

- Highly nonlinear relationship between yields and temperature
- Increase in mean temperature
  - Reduction in average yields
    - Increase in frequency of extreme heat
  - Increase in yield variability
    - Even if weather variability does not change
    - Relationship between yields and weather have higher curvature
    - Same weather fluctuation result in larger yield swings
- Will food prices become more variable?
  - Calibrate a storage model
  - Storage driven by arbitrage between periods
    - If production more variable, incentive to hold more stock
    - Higher stock levels: higher average price as storage costly, but less variability

Adaptation: Storage can Smooth Variability



Adaptation: Storage can Smooth Variability



Outline

Conclusions

- Statistical study linking yields and weather
  - Driving force: extreme heat
  - Large yield decline if maximum temperature rises a lot
  - Potential offsetting beenfits of CO_2
- Agronomic evidence
  - APSIM model
  - Extreme heat has larger effects on yields than precipitation
- Adapting to extreme heat
  - Seems costly and first-order effect likely to be small
    - Consistent with envelope theorem
    - Farmers maximized their production process
    - First-order adaptation effects are zero
  - Disincentives for adaptation due to crop insurance
  - Most likely is shift ingrowing area
- Variability of production
  - Adaptation fairly easy through storage