Agriculture: Empirical estimates of impacts

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Columbia University and NBER

Snowmass - July 23 2014

Outline

1. Modeling US Yields
2. Water versus Temperature
3. Yields in Africa
4. Climate Change and Global Production Trends
5. Adoption to Production Variability
6. Conclusions

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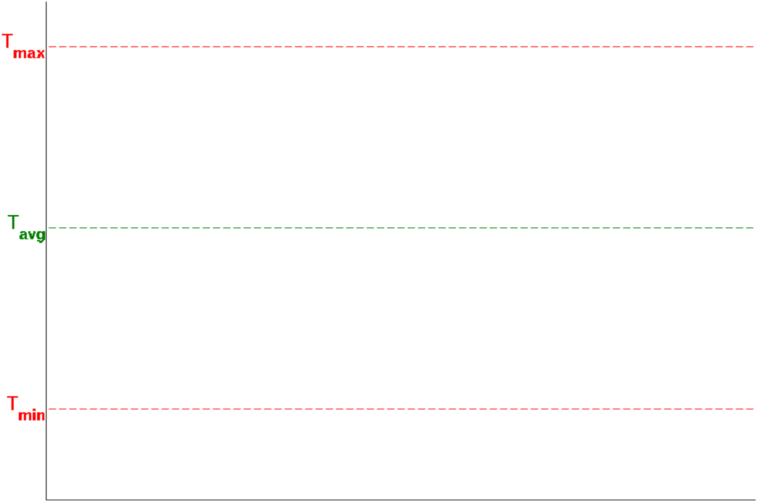
Construction of Degree Days



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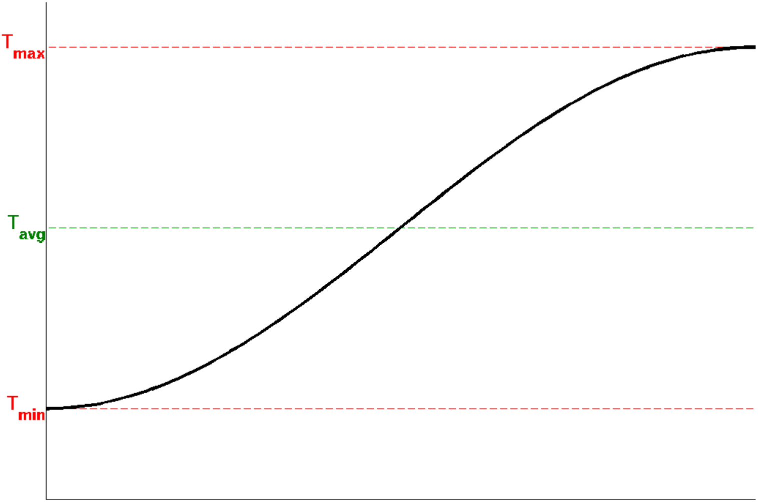

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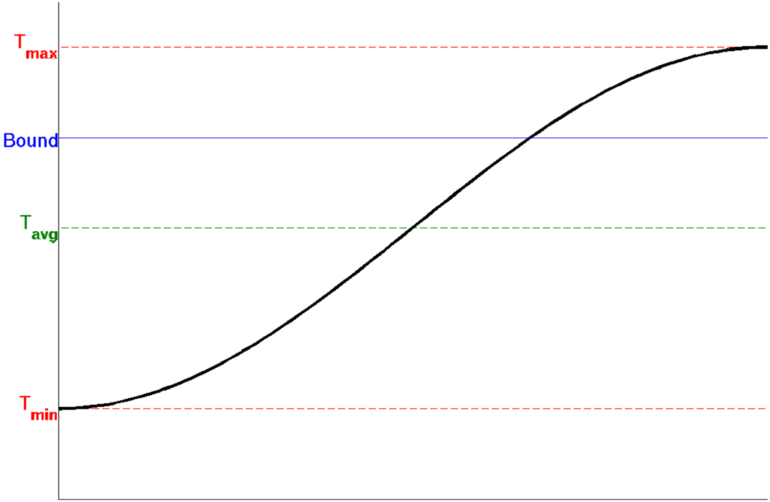

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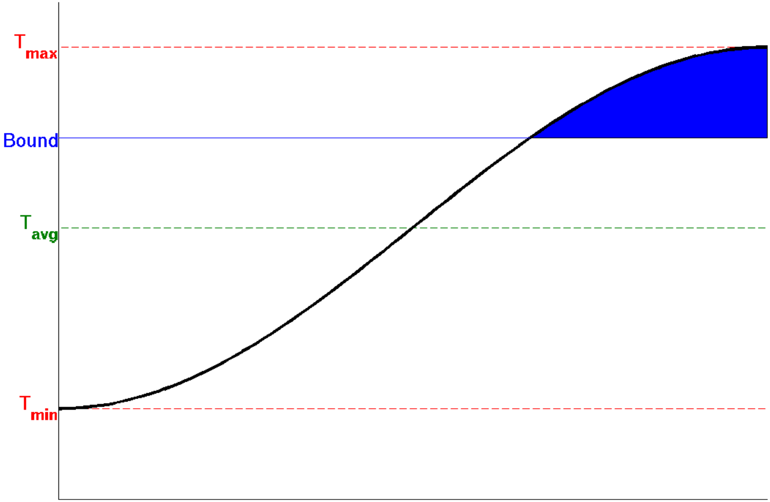

Link between Temperature and US Yields

- 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

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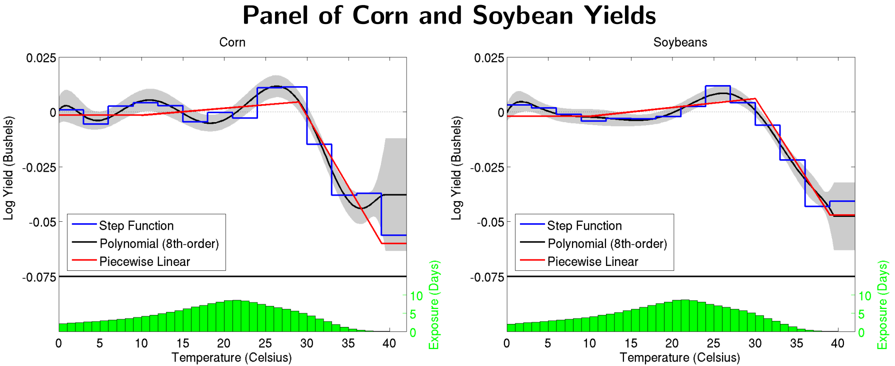
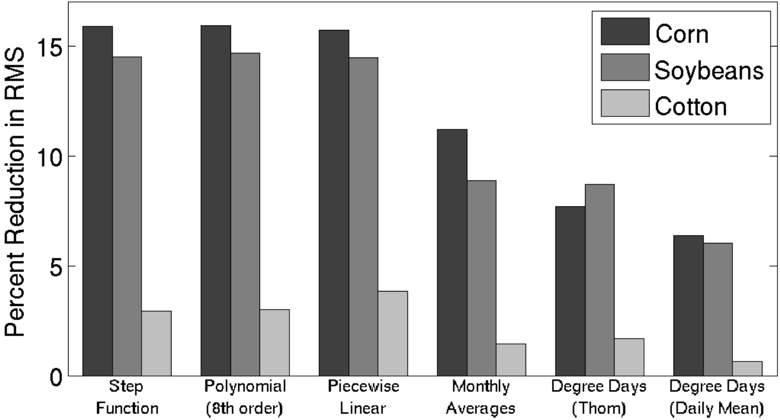
    - Fine-scale weather (daily temperature / precip on 2.5mile grid)
    - Years: 1950-2005
- Model accounts for
    - Amount of time spent in each 1°C interval
    - Quadratic in total precipitation
    - State-specific quadratic time trends
    - County fixed effects

Results: Effect of Weather on Yields



Schlenker & Roberts (PNAS 2009)

Comparing Models: Reduction in Prediction Error



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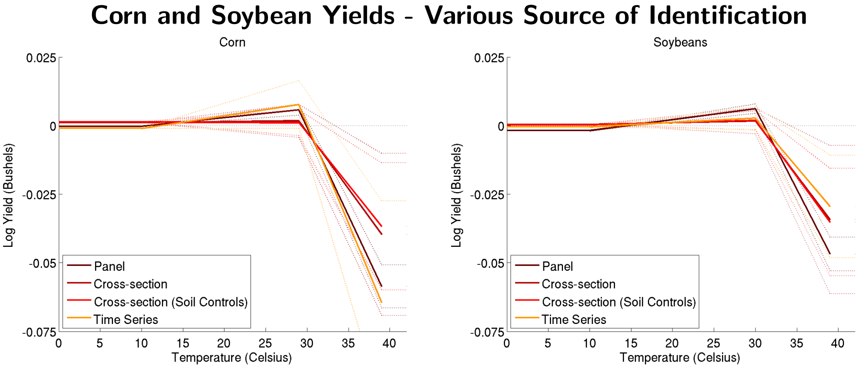
Comparing Models: Reduction in Prediction Error

	(0a)	(0b)	(1a)	(1b)	(2a)	(2b)	(3a)	(3b)	(4b)
Average Temperature (Celisus)	0.029***	0.038***							
	(0.007)	(0.011)							
Average Temperature Squared	-0.001***	-0.002***							
	(0.000)	(0.000)							
Degree Days 10-29° C (Thousand)			-0.061***	-0.035*	0.080***	0.137***	0.072**	0.127***	0.277***
			(0.018)	(0.019)	(0.027)	(0.031)	(0.026)	(0.030)	(0.090)
Degree Days 29° C (Hundred)			-0.109***	-0.150***	-0.098***	-0.126***	-0.103***	-0.133***	-0.544***
			(0.024)	(0.036)	(0.011)	(0.015)	(0.012)	(0.016)	(0.068)
Precipitation (m)	1.939***	2.981***	1.312***	1.702***	0.965***	1.301***	0.958***	1.286***	0.871***
	(0.230)	(0.411)	(0.244)	(0.427)	(0.258)	(0.447)	(0.257)	(0.445)	(0.248)
Precipitation Squared (m^2)	-1.313***	-2.130***	-0.895***	-1.208***	-0.776***	-1.086**	-0.765***	-1.066**	-0.696***
	(0.187)	(0.364)	(0.198)	(0.378)	(0.213)	(0.397)	(0.212)	(0.397)	(0.204)
R-squared	0.3683	0.3680	0.3882	0.3934	0.4023	0.4065	0.4030	0.4073	0.5063
Out of Sample RMSE (% Reduction)	11.58	9.74	12.68	15.15	11.05	17.03	13.63	16.43	29.56
Observations	60148	60148	60148	60148	60148	60148	60148	60148	60148
Counties	2216	2216	2216	2216	2216	2216	2216	2216	2216
Years	33	33	33	33	33	33	33	33	33
Temp in Degree Day Calculation	-	-	Average	Average	3-Hour	3-Hour	Lin Int	Lin Int	Full Day
Weather Data	NARR	NARR	NARR	NARR	NARR	NARR	NARR	NARR	SR(2009)
Interpolation	Centroid	Surface	Centroid	Surface	Centroid	Surface	Centroid	Surface	Surface

Comparison to Massetti et al.

Results: Source of Variation



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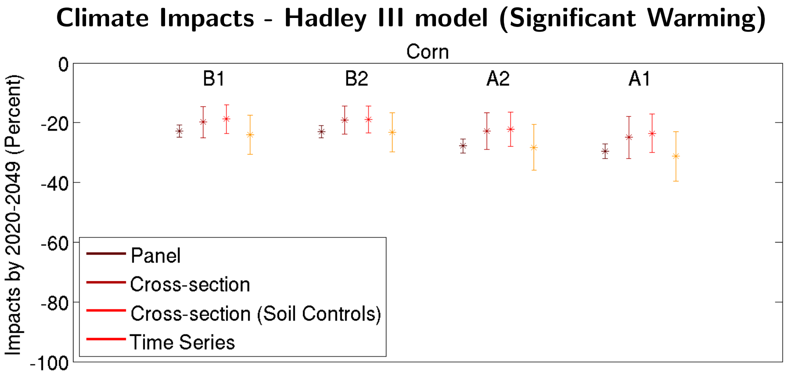
Results: Climate Impacts Part I



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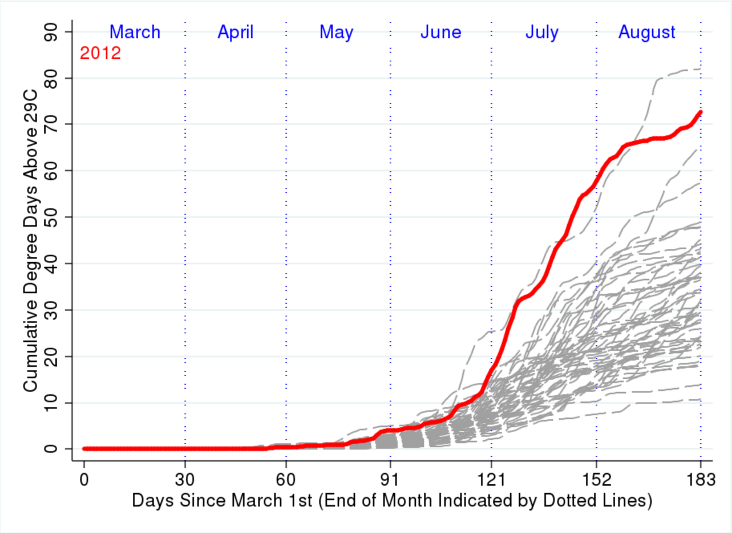
Results: Climate Impacts Part II

Climate Impacts - Uniform Scenarios

	Corn			Corn	
	Impact	**s.e.**		**Impact**	**s.e.**
Temperature +1°C	-6.38	(0.53)	Precipitation -50%	-10.44	(1.47)
Temperature +2°C	-14.87	(1.02)	Precipitation -40%	-7.43	(1.12)
Temperature +3°C	-24.76	(1.47)	Precipitation -30%	-4.85	(0.79)
Temperature +4°C	-35.30	(1.84)	Precipitation -20%	-2.73	(0.49)
Temperature +5°C	-45.75	(2.21)	Precipitation -10%	-1.10	(0.23)
Temperature +6°C	-55.88	(2.66)	Precipitation +10%	+0.57	(0.20)
Temperature +7°C	-65.19	(3.12)	Precipitation +20%	+0.60	(0.38)
Temperature +8°C	-73.42	(3.56)	Precipitation +30%	+0.09	(0.55)
Temperature +9°C	-80.26	(3.87)	Precipitation +40%	-0.95	(0.73)
Temperature +10°C	-85.86	(4.07)	Precipitation +50%	-2.50	(0.92)

Schlenker & Roberts (PNAS 2009)

Recent Example: 2012 Heat Wave / Drought



Berry, Roberts & Schlenker (2013)

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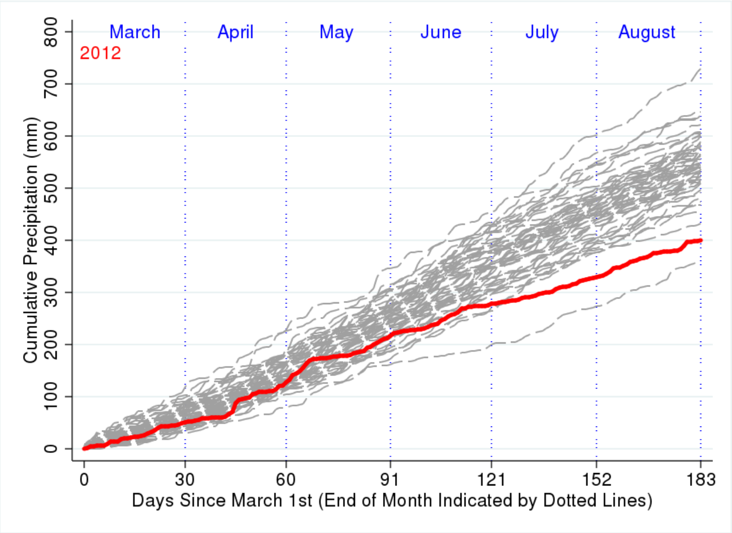

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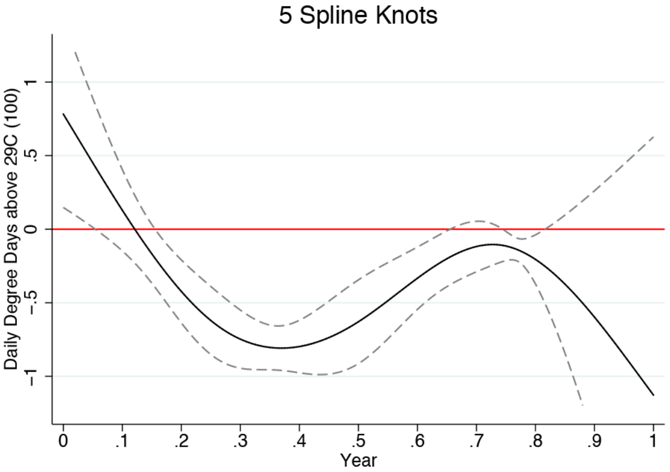
Recent Example: 2012 Heat Wave / Drought

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



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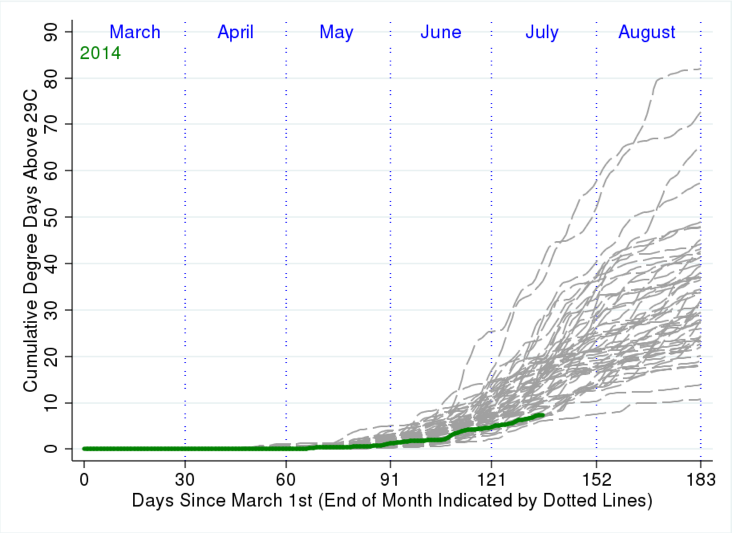
Allowing for Interactions that Can Evolve Over Season

	(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)

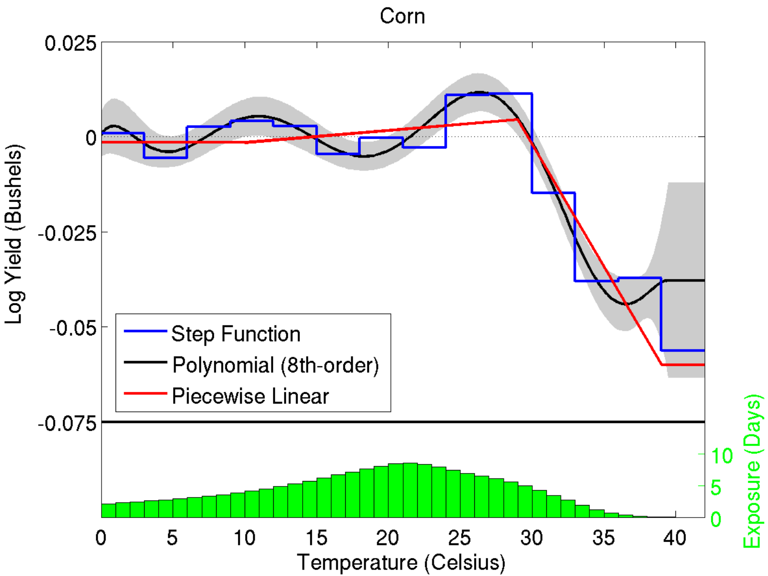
What About 2014?



What About 2014?

Outline

Agronomic Evidence on Mechanism



Agronomic Evidence on Mechanism

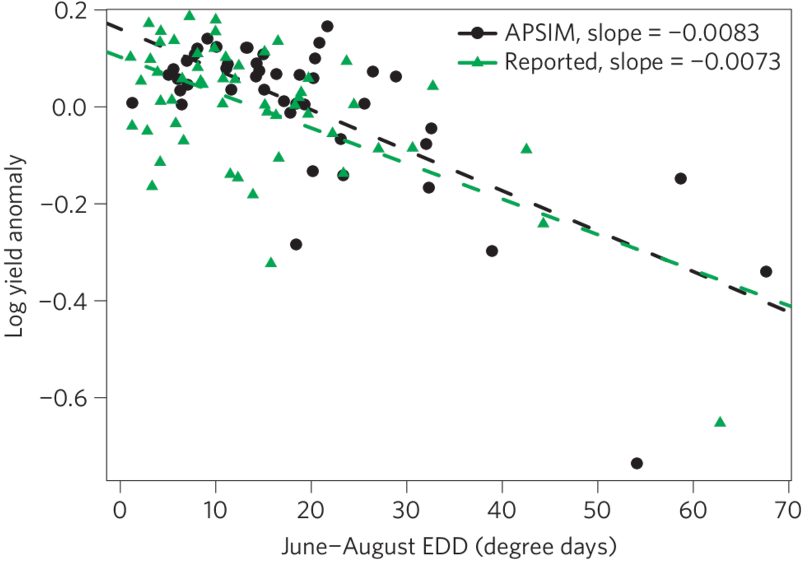
- Biophysical evidence
  - Lobell, Hammer, McLean, Messina, Roberts, Schlenker (2013)
    - APSIM: biophysical model of crop growth
    - Includes water balance, etc
- Mechanism behind EDD (Extreme degree days)
  - Impacts water stress in two ways
    - Reducing soil water (evaporation)
    - Increased 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

Water versus Temperature: Chicago Marathon (2007) in Hot Weather

Water versus Temperature: Chicago Marathon (2007) Ran Out of Water

Heat versus Water



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Statistical Study in Africa: Schlenker and Lobell (2010)

- Panel of country-level yields (FAO)
  - Matched with weather data (CRU, NCC)
  - Averaged over area where crop is grown
    - Monfreda, Ramankutty & Foley 2008
  - Averaged over crop-specific growing season
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- Major crops in Africa
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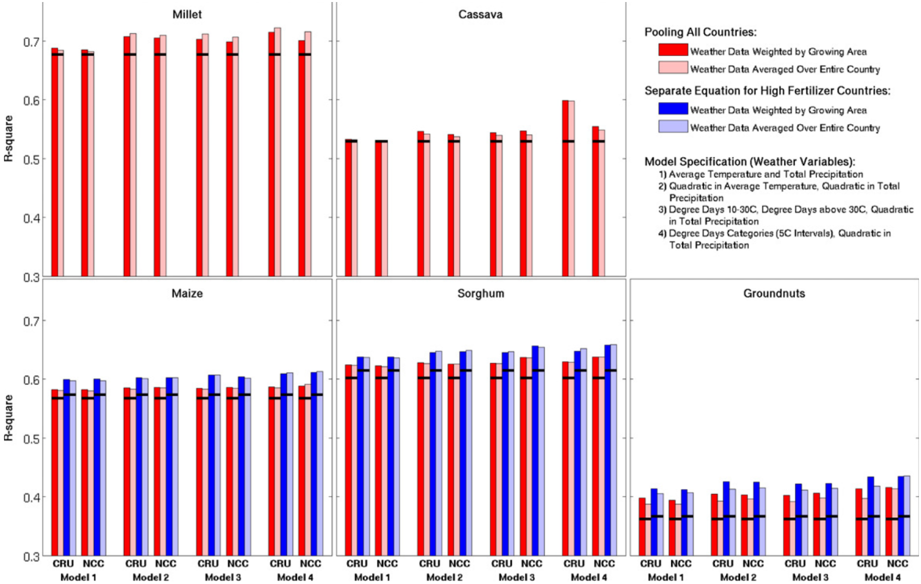
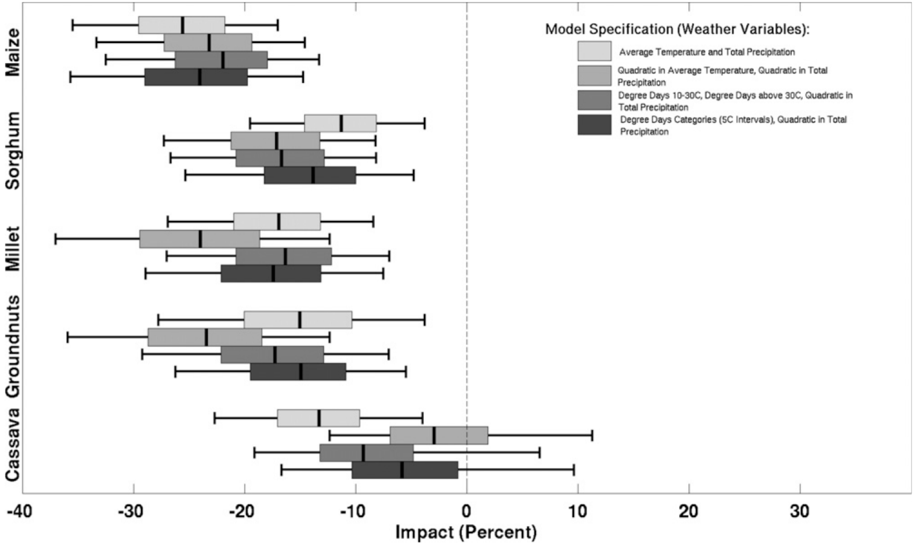
- Two models
  1. Average temperature and total precipitation
  2. Degree days and total precipitation

  - Challenge: Weather data has significant measurement error
  - Difficult to get nonlinearity right!
  - Neither model gives significantly better predictions

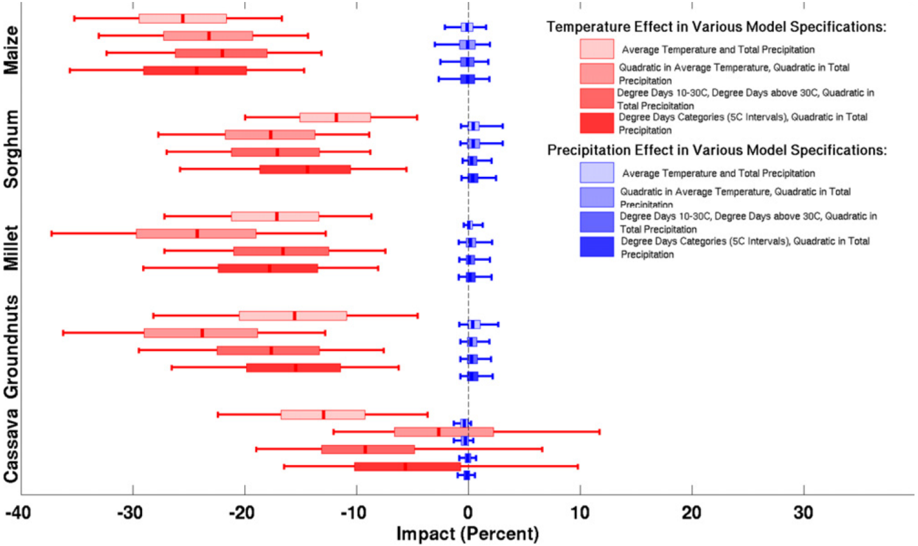
Statistical Study in Africa: Model Comparison



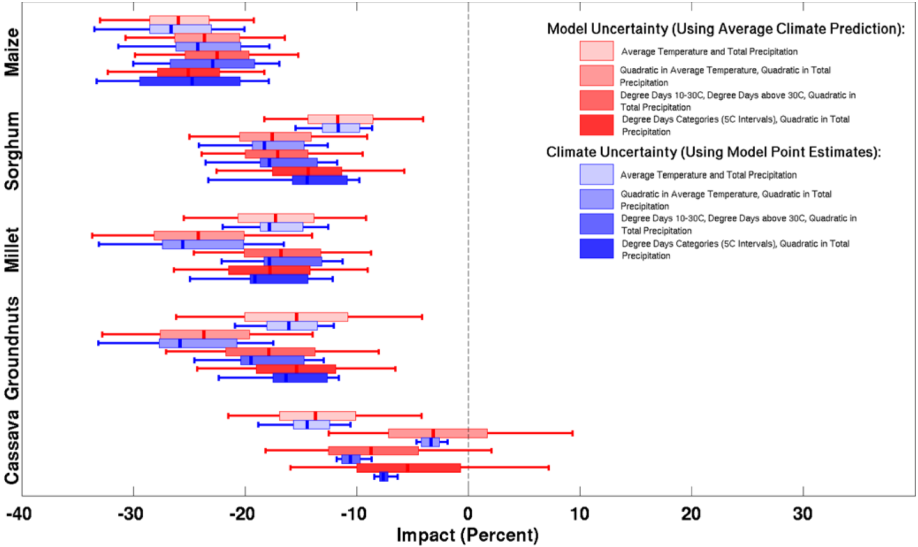
Predicted Impact of Warming (2046-2065)



Separating Impact Due to Temperature and Precipitation



Separating Model and Climate Uncertainty



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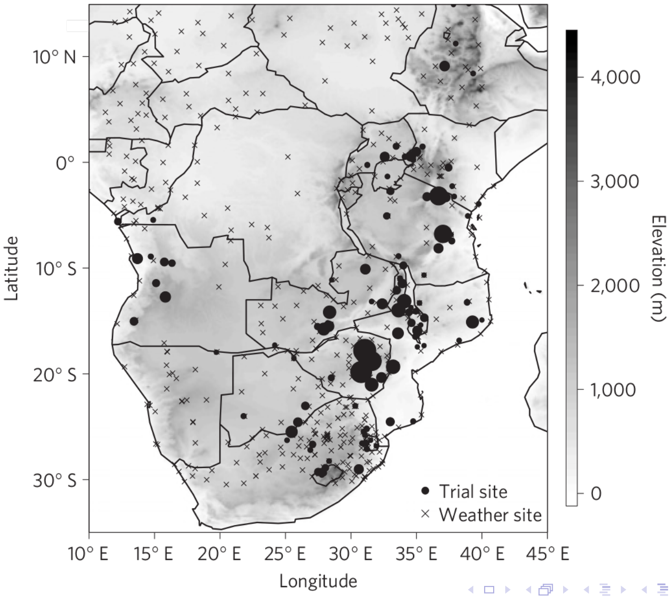
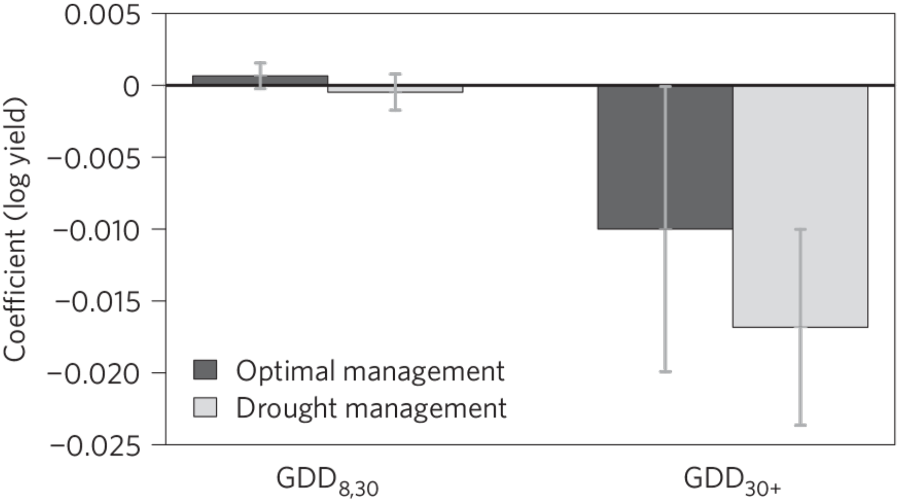
- Major results
    - Find nonlinearity effect of temperature on yield
    - Stronger under drought conditions

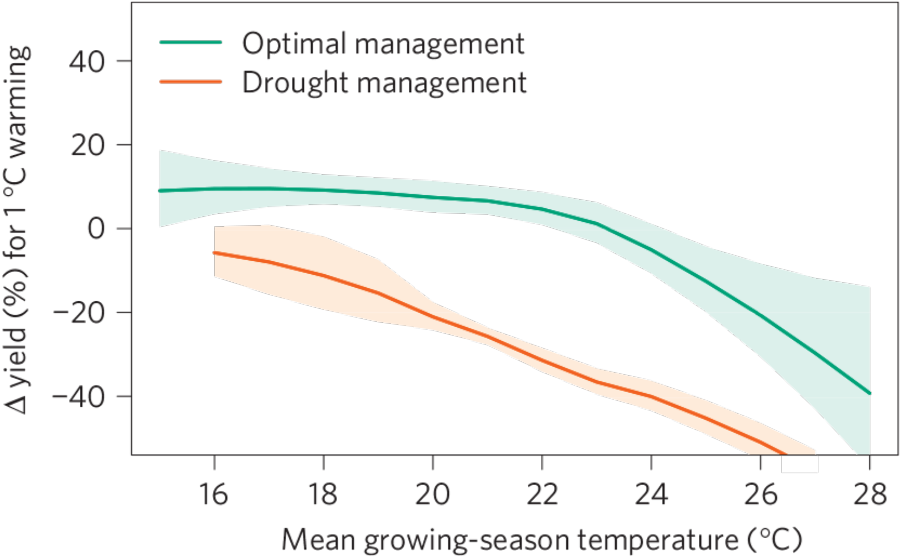
Location of Field Trials



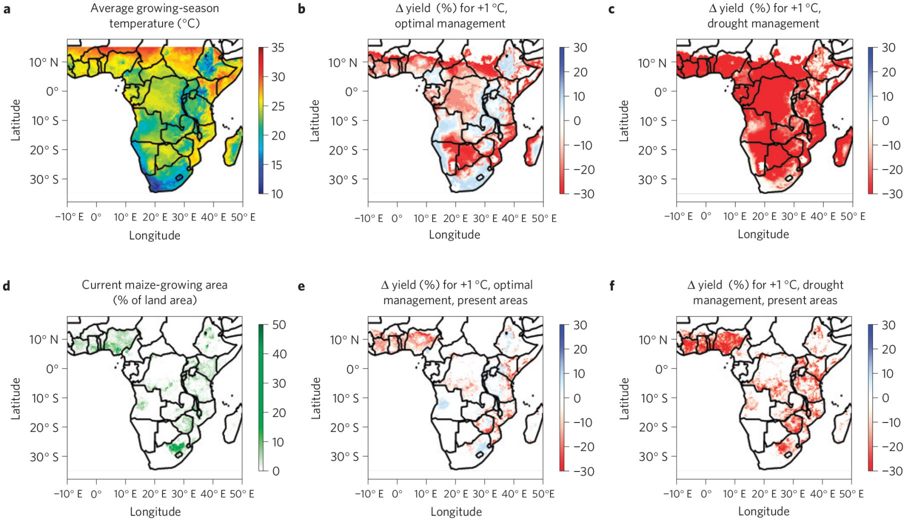
Regression Coefficients for Temperature



Simulating 1°C Warming



Geographic Distribution of Impacts



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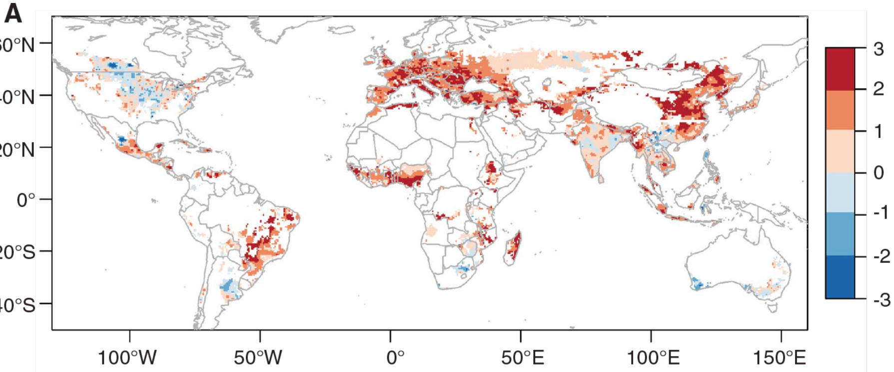
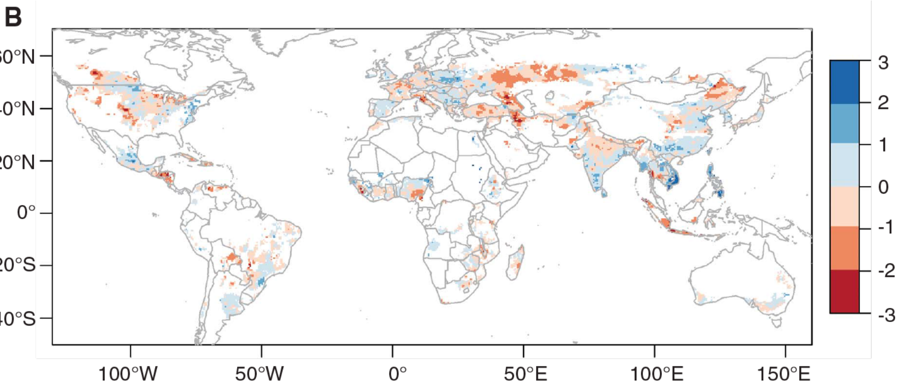
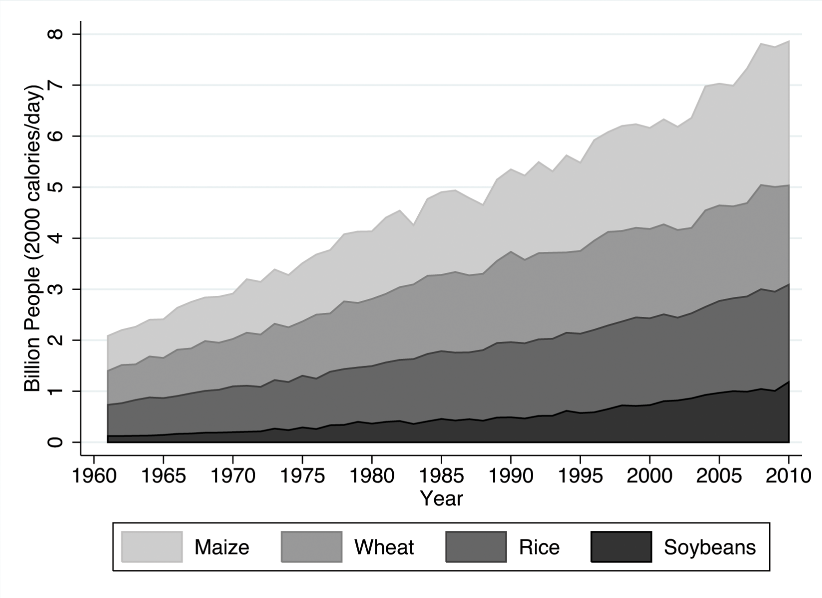
Temperature Trend (1980-2008) in Historic Std. Deviation



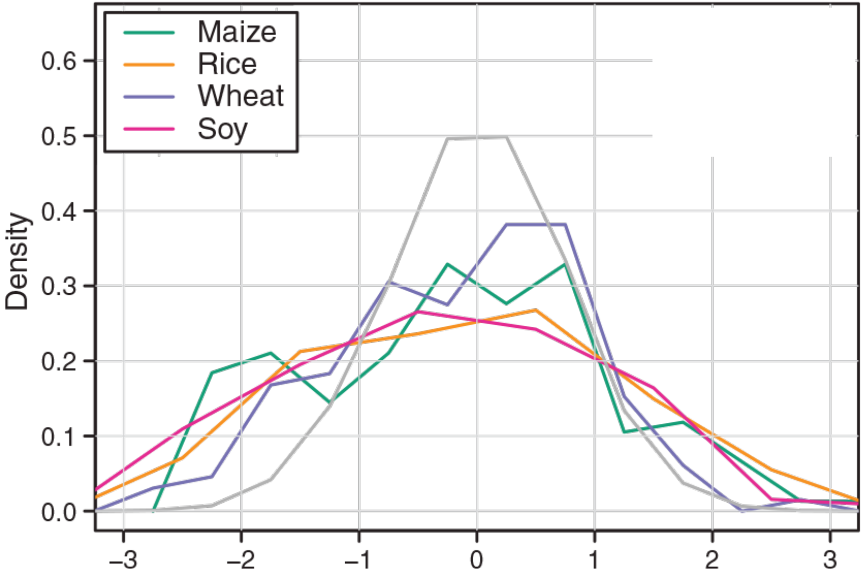
Precipitation Trend (1980-2008) in Historic Std. Deviation



Global Production: 1961-2010



Country-Crop Specific Temperature Trends (1960-1980)



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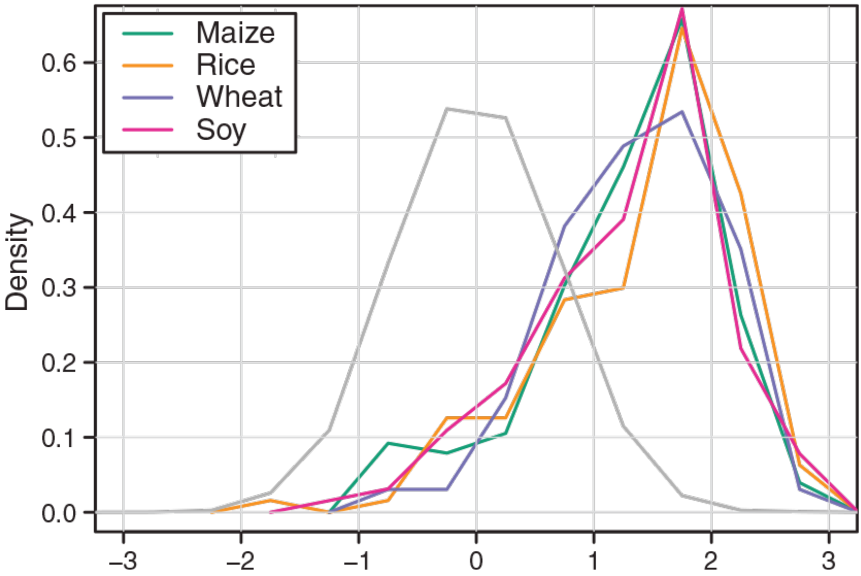
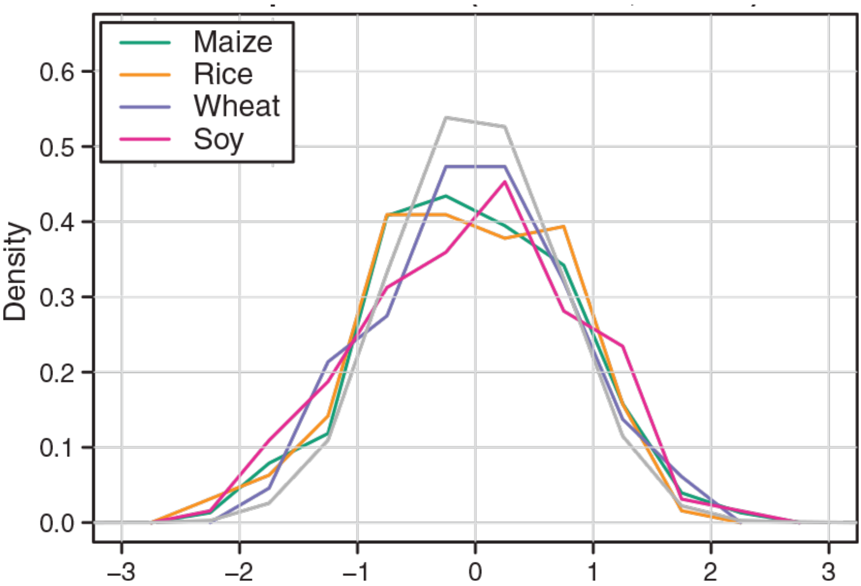


Country-Crop Specific Precipitation Trends (1980-2008)



Predicted Impact of Observed Trend

Crop	Global production, 1998–2002 average (millions of metric tons)	Global yield impact of temperature trends (%)	Global yield impact of precipitation trends (%)	Subtotal	Global yield impact of CO_2 trends (%)	Total
Maize	607	−3.1 (−4.9, −1.4)	−0.7 (−1.2, 0.2)	−3.8 (−5.8, −1.9)	0.0	−3.8
Rice	591	0.1 (−0.9, 1.2)	−0.2 (−1.0, 0.5)	−0.1 (−1.6, 1.4)	3.0	2.9
Wheat	586	−4.9 (−7.2, −2.8)	−0.6 (−1.3, 0.1)	−5.5 (−8.0, −3.3)	3.0	−2.5
Soybean	168	−0.8 (−3.8,1.9)	−0.9 (−1.5, −0.2)	−1.7 (−4.9, 1.2)	3.0	1.3

Combined Price Effect: 18.9% (no CO_2 fertilization), 6.4% (including CO_2 fertilization)

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

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    - Relationship between yields and weather have higher curvature
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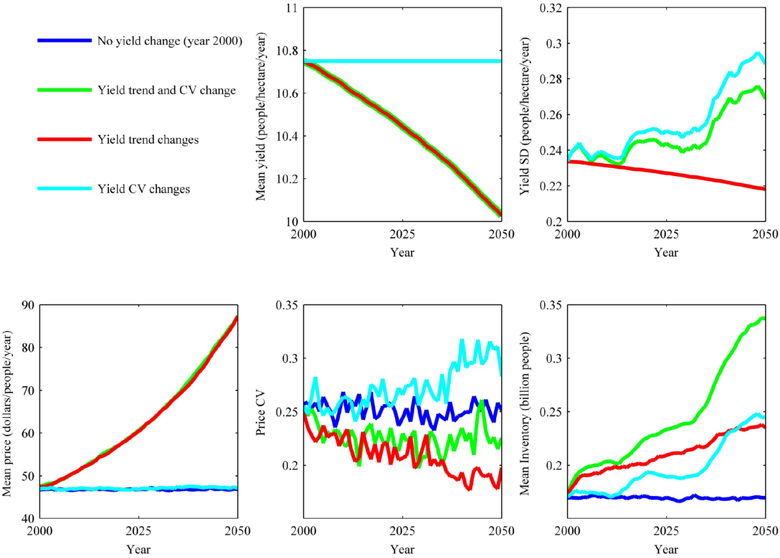
- Will food prices become more variable?
  - Calibrate a storage model
  - Storage driven by arbitrage between periods
    - If production more variable, incentive to hold more stock
    - Higher stock levels: higher average price as storage costly, but less variability

Adoption: Storage can Smooth Variability



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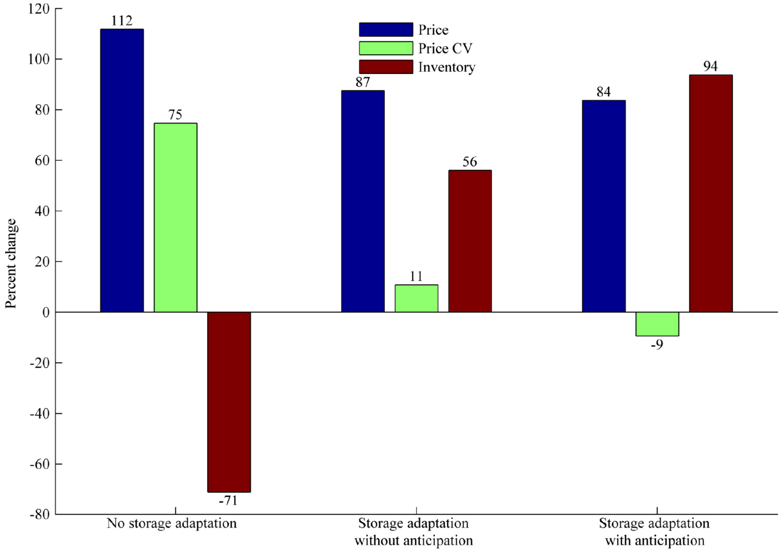

Outline

Conclusions

- Statistical studies of climate change
  - Driving force: extreme heat
  - Large yield decline if maximum temperature rises a lot
  - Impact depends on baseline and predicted increase
  - Adoption to extreme heat difficult: most likely is shift of growing area
- Agronomic evidence
  - APSIM model
  - Extreme heat has larger effects on yields than precipitation
- Observed temperature trends 1980-2008
  - Already have effect on global food prices
- Variability
  - Adoption fairly easy through storage
- Slides available at: http://wolfram-schlenker.com/Snowmass.pdf