Climate change and agriculture: Farmer adaptation to extreme heat

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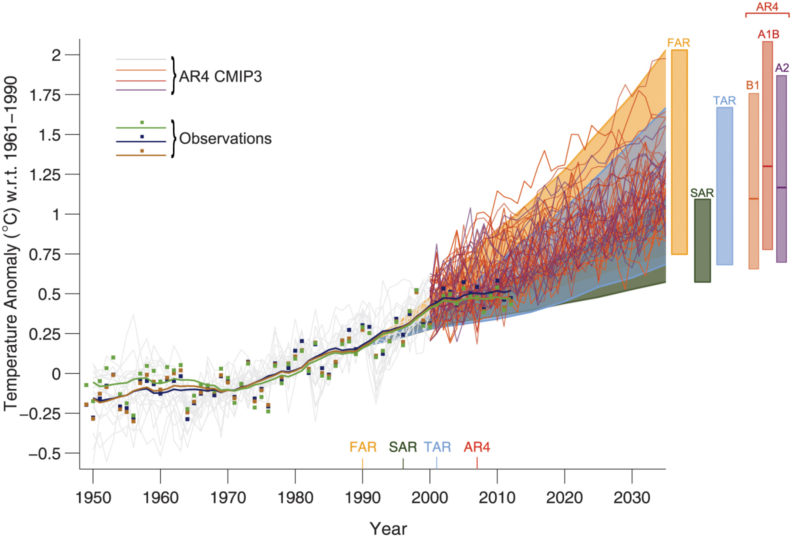
Academia Nacional de Ciencias Económicas - Junio 2018

Climate Change and Extreme Temperatures



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Climate Change in Developing Countries

A rise in average temperatures and an expected increase in extreme weather events in a context of vulnerability

- Rural poverty
- Subsistence, traditional farming is the main economic activity
- Poorly developed markets (e.g. no insurance)

Research questions

Focus on consumer-producer households in developing countries

- What are the margins for adaptation available to farmers?
  - Productive responses and ex-post consumption-smoothing instruments
  - Who adapts?
- Accounting for adaptation in climate change predictions.

What we know

- Non-linear relationship between temperatures and yields
  - Usually explored with aggregate data, such as districts or counties (Deschenes & Greenstone 2007; Roberts & Schlenker 2009; IMF WEO 2017; Burgess et al. 2017).
- Little evidence of productive mitigation strategies being at place in the farm (Burke & Emerik 2016; Guiteras 2009).
- Evidence from developing countries
  - Adaptation: self-reported shocks (Hisali et al. 2011); coarse measures (Di Falco et al. 2011).
  - Weather shocks and changes in livestock, migration, child labor, off-farm employment (Rosenzweig and Wolpin 1993; Munshi 2003; Beegle et al 2006; Kochar 1999).

Our Approach: Adaptive responses in production

1. We use rich agricultural data for household farms in Peru (2007-2015) to unpack the effect of extreme temperature on yields
   - Yields are $Y(A, T, L)/T$: comprises biological and human responses.
   - A production function approach: We model the shock as a reduction in TFP that can affect both Y and T
2. We use high frequency satellite data on temperatures and precipitation, geo-matched with households.
   - To overcome data constraints: e.g. no monitoring stations in rural areas; monthly averages temperatures absorb important variation

Our Approach: Adaptive responses in production

3. We explore farmer heterogeneity to understand adaptive responses to extreme temperature events.

4. We simulate impacts on output under different standard climate change scenarios using our estimates
   - We highlight the importance of accounting for regional variation in climate.
   - We account for adaptation.

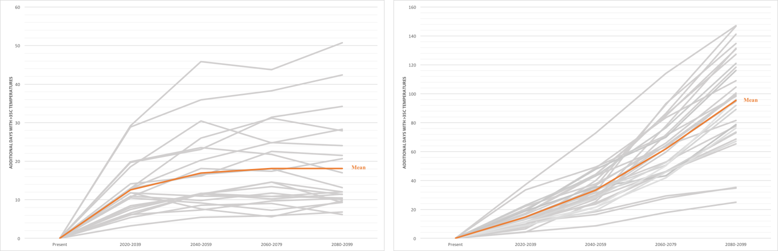
Our Results

- We find a robust increase in land use and household labor when farmers are exposed to extreme temperature
  - We document negative effects of extreme temperature on yields, TFP and output
- Who adapts?
  - Farmers that do not have alternative instruments: for those that had livestock or non-agricultural income, land use is unchanged.
- Two findings from our simulation of climate change scenarios:
  - The importance of accounting for regional variation: only hotter areas suffer from increased temperatures
  - The importance of accounting for adaptation: Effects on output may be overestimated

Context: Rural Peru

- Rural poverty rate is >50%
- Households generally farm small parcels of land (< 3 ha)
- Diverse climatic regions and agricultural practices
- Predicted increase in extremely hot days (Source: Climate Change Knowledge Portal, World Bank)

Figure: Predicted increase in number of days with T>35



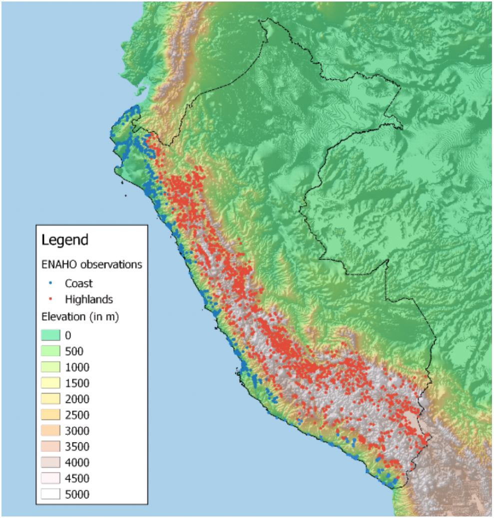
(a) RCP2.6 (b) RCP8.5

Data

- ENAHO 2007-2015: HH survey with sample of 55K farmers in the coast and highlands of Peru.
- Daily average daytime land surface temperatures (LSTs) from NASA at 5.6km x 5.6km squares (MODIS)
- Monthly precipitation rates from reanalysis at 5.6km x 5.6km squares (CHIRPS)
- Soil quality data at a 9km x 9km grid (IIASA - FAO)

Rural Peru: households

Figure: Agricultural survey observations



Summary Statistics

Variable	All sample (1)	Coast (2)	Highlands (3)
HoH main job is agriculture (%)	78.4	68.6	80.1
Poor (%)	50.8	26.2	55.0
Child labor (%)	21.5	9.5	23.6
B. Agricultural characteristics			
Value of agric. output (Y)	1025.3	3053.0	682.0
Output per ha. (Y/T)	1256.3	2319.3	1077.3
Uncultivated land (% land holding)	40.1	12.1	44.8
Irrigated land (% land holding)	36.4	82.3	28.7
Tubers (% total output)	31.4	5.6	35.6
Grains (% total output)	31.2	30.2	31.4
Value of livestock, 2007 USD	678.10	450.30	716.67
C. Weather in last growing season			
Average temperature (C)	22.9	33.1	21.2
Precipitation (mm/day)	3.1	0.9	3.5
No. Obs.	54,981	7,961	47,020

Analytical framework

- The botanical literature has established long ago that very high temperatures are harmful for plant growth.
- That would mean that, conditional on inputs (land T and labor L), output Y decreases with extreme temperature: this is a TFP shock.
- Most of the literature focuses on how extreme temperature affects yields Y/T.
- However, we need to be explicit about constraints farmers face to rationalize a drop in yields, e.g. is land fixed in the short run?
- How is the farming environment different for small household farmers in developing countries?

Analytical framework: some key features

- Farmers are close to subsistence
- Main inputs are endowments: owned land and household labor
- Limited outside opportunities
- Little specialization: crop rotation and fallow (optimal to have uncultivated land)

Implications

A negative TFP shock can *increase* household inputs, unless alternative instruments for consumption smoothing are available.

Empirical Approach

- Starting from a Cobb-Douglas production function, estimate:

$$\ln Y_{ivt} = \alpha \ln T_{it} + \beta \ln L_{it} + \underbrace{g(\gamma, \omega_{it}) + \phi Z_i + \rho_j + \psi_t}_{\ln \text{TFP}} + \xi_{ivt}$$

- Y: annual agricultural output (in constant prices)
- T: land used; L: labor (hours, wage bill)
- IV: use land and labor endowments as instruments for inputs (i.e. land owned and household size)
- $g(\gamma, \omega_{it})$: Non linear function of the weather
- $\phi Z_i + \rho_j + \psi_t$: District and growing season FE + controls (soil, HH charact.)

Empirical Approach

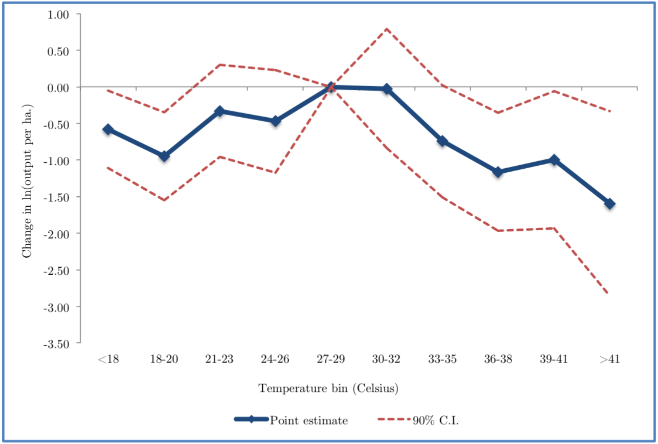
We model $g(\gamma, \omega_{it})$ following the literature (Schlenkler & Roberts 2006, Deschenes & Greenstone 2007, among others):

- Temperature:
  - Cumulative exposure to heat has a non-linear effect
  - Good temperature: Degree days (DD): 8 - τ_{High}
  - Harmful temperature: harmful degree days (HDD): above τ_{High}
  - We estimate the threshold τ_{High} using a bin approach: run log yields on a vector of variables measuring the proportion of days in a given temperature bin.
- g enters our estimation as

$$g(\gamma, \omega_{it}) = \underbrace{\gamma_0 DD_{it} + \gamma_1 HDD_{it}}_{\text{temperature}} + \underbrace{\gamma_2 PP_{it} + \gamma_3 PP_{it}^2}_{\text{precipitation}}$$

Results: Temperature and yields

We use 36 °C as threshold



Notes: Points represent coefficient estimates of the effect of increasing the share of days in the growing season in each of the temperature bins, relative to the 27-29°C bin, on log of output per ha.

Impacts of HDD on agricultural productivity and output

	Y/T	TFP		Y
Dep var:	ln(output/ha)	ln(output)	ln(output)	ln(output)
	(1)	(2)	(3)	(4)
Average DD	0.009	0.007	0.009	0.006
	(0.009)	(0.008)	(0.008)	(0.009)
Average HDD	-0.192***	-0.164***	-0.181***	-0.157**
	(0.070)	(0.063)	(0.064)	(0.075)
Input controls	No	OLS	IV	No
N	54,981	54,972	54,972	54,981
R2	0.241	0.405	0.390	0.244

Impacts of HDD on Input use

	Hired Labor	T	Household Labor		
	(1)	(2)	(3)	(4)	(5)
Dep var:	Wage Bill	Land Used	HH members in farm	HH Hours in farm	Child Labor
Average DDs	0.017	-0.003	-0.008*	-0.019***	-0.020***
	(0.014)	(0.005)	(0.004)	(0.007)	(0.006)
Average HDDs	-0.151*	0.035**	0.066***	0.084**	0.045**
	(0.082)	(0.015)	(0.022)	(0.036)	(0.020)
N	54,979	54,981	22,500	22,503	11,990
R2	0.222	0.313	0.261	0.257	0.308

HDD and Crop Mix

Dep var:	ln(output)			Share of total output		
	(1)	(2)	(3)	(4)	(5)	(6)
Crop group:	Cereals	Tubers	Legumes	Cereals	Tubers	Legumes
Average DD	0.044***	-0.079***	0.019**	0.011***	-0.026***	0.002*
	(0.009)	(0.015)	(0.009)	(0.002)	(0.003)	(0.001)
Average HDD	-0.207***	0.182***	0.012	-0.031***	0.036***	0.004
	(0.061)	(0.056)	(0.056)	(0.011)	(0.007)	(0.007)
N	43,251	40,131	34,335	54,214	54,214	54,214
R2	0.454	0.391	0.318	0.380	0.520	0.239

Summary: Effects of Extreme Temperatures

- A drop in TFP, output and yields.
- Farmers use more land
  - One standard deviation increase in HDD increases land use by 2.8 %.
  - 18% of the drop in yields is explained by an increase in the productive use of land.
- Households resort to household labor, including children, and reduce their expenses in market labor.
- Increase in tuber production
  - Cheaper calories?
  - Results on output and inputs sizeable despite this - a limited role?

Consumption Smoothing

Households reduce their livestock holdings

	Off-farm work	Migration		Livestock buffer			
Dep var:	HH member has off-farm job	HH member away 30+ days	Receives private transfers	Decrease in livestock value	Sold livestock	Consumed livestock	Current livestock value
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Average HDD	-0.007	-0.003	-0.001	0.028***	0.024*	0.009	-34.12*
	(0.021)	(0.004)	(0.009)	(0.010)	(0.013)	(0.013)	(20.17)
N	22,503	54,981	54,981	49,094	49,094	49,094	41,745
$R2$	0.223	0.057	0.148	0.078	0.146	0.239	0.553

Who adapts?

Households with no other options

	Livestock		Farmer Only	
	(1)	(2)	(3)	(4)
Dep var:	ln(land used)	TFP	ln(land used)	TFP
Average HDD x owned livestock	0.019	-0.175***		
	(0.016)	(0.067)		
Average HDD x no livestock	0.042***	-0.173***		
	(0.015)	(0.065)		
Average HDD x Other activity			-0.003	-0.311***
			(0.015)	(0.072)
Average HDD x Farmer only			0.048***	-0.106*
			(0.016)	(0.059)
Difference	0.023	0.002	0.051	0.205
p-value	0.030	0.956	0.000	0.000
N	54,981	54,972	54,981	54,972
R2	0.326	0.410	0.323	0.412

When do they adapt? early vs late shocks

	Y/T	TFP		Y	T
Dep var:	ln(output/ha)	ln(output)	ln(output)	ln(output)	ln(land used)
	(1)	(2)	(3)	(4)	(5)
Average Early HDD	-0.067**	-0.064*	-0.076**	-0.036	0.031**
	(0.038)	(0.035)	(0.036)	(0.067)	(0.013)
Average Late HDD	-0.126*	-0.103*	-0.109*	-0.119*	0.007
	(0.063)	(0.061)	(0.060)	(0.015)	(0.015)
Input controls	No	OLS	IV	No	No
N	54,938	54,929	54,929	54,938	54,938
R2	0.241	0.405	0.391	0.244	0.313

Adaptive response or change in prices?

Dep. var:	ln(land used)		ln(regional price)		ln(local price)	
			Cereals	Tubers	Cereals	Tubers
	(1)	(2)	(3)	(4)	(5)	(6)
Average DD	-0.004	-0.004	0.000	-0.002*	-0.003	-0.001
	(0.005)	(0.005)	(0.002)	(0.001)	(0.002)	(0.002)
Average HDD	0.038**	0.043**	0.022*	0.009**	0.004	0.007
	(0.016)	(0.018)	(0.012)	(0.005)	(0.008)	(0.016)
Region-GS FE	Yes	No	No	No	No	No
Control for local prices	No	Yes	No	No	No	No
N	54,981	50,836	54,981	54,981	52,739	52,447
R2	0.320	0.319	0.931	0.910	0.757	0.667

Adaptation

- Livestock farmers are on average poorer and more likely to have resting land: still, they do not expand land
- Same results if using a measure of off-farm labor: land increases only for those relying exclusively on agricultural production.
- Results on land use cannot be fully explained by changes in crop mix or agricultural output prices

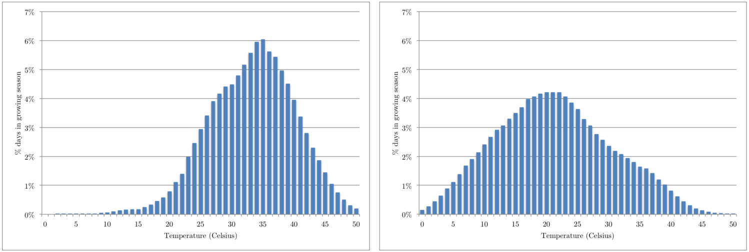
Climate Change scenarios

- We consider two possible scenarios with increase in average temperature of 1.5°C and 3°C (IPCC, 2014)
  - Climate change scenarios are contingent on assumptions about behavioral change (e.g. fossil fuel emissions).
  - While economic theory suggests that farming technologies are more flexible in the long run, allowing for adaptation, researchers failed to find evidence, e.g. Burke and Emerick (2016), Burke et al. (2015), Guiteras (2009)
- We uniformly distribute our additional degrees and compute new values of DD and HDD
- We estimate predicted changes in output (i.e. after adaptation) and yields using our regression results
- Yields: equivalent to simulating effects obtained from agronomic lab experiments or using estimates from developed countries.

Climate Change Scenarios: Regional Variation

- Diverse climatic regions and agricultural practices
  - Coast: sub-tropical, hot, arid (< 1 mm/day)
  - Highlands: high altitude, cool, wet (> 3.5 mm/day)

Figure: Distribution of daily average temperature



(a) Coast (b) Highlands

Climate Change Scenarios: Regional Variation

No differential impact by region

Dep var:	ln(output per ha)			ln(land used)		
Region:	Coast	Highlands		Coast	Highlands	
	(1)	(2)	(3)	(4)	(5)	(6)
Average DD	0.004	0.007		0.001	-0.004	
	(0.040)	(0.008)		(0.010)	(0.006)	
Average HDD	-0.195**	-0.169*		0.024*	0.085*	
	(0.082)	(0.087)		(0.014)	(0.047)	
Difference in HDD impact Highlands-Coast			0.012			0.057
			(0.121)			(0.047)
N	7,961	47,020	54,981	7,961	47,020	54,981
R2	0.194	0.269	0.242	0.223	0.325	0.313

Predicted effects on agricultural yields and output

CC scenario:	Scenario +1.5 Celsius			Scenario +3 Celsius		
Sample:	All (1)	Coast (2)	Highlands (3)	All (4)	Coast (5)	Highlands (6)
Effect on temperature over the growing season						
A. Average DD	1.383	1.007	1.450	2.724	1.833	2.881
B. Average HDD	0.103	0.493	0.034	0.255	1.167	0.095
Effect on agricultural productivity and output						
C. Change in productivity (ln(Y/T))	-0.010	-0.092	0.005	-0.029	-0.220	0.005
D. Change in output (ln(Y))	-0.010	-0.079	0.002	-0.027	-0.190	0.002
Over-estimation of effect in Y (|D-C|)	0.000	0.013	0.003	0.002	0.030	0.003

Climate Change Predictions

- Increase in temperatures hit regions differently: hotter Coast gets ‘harmful’ additional degrees, the cooler highlands gets ‘good’ degrees
- As a consequence, the Coast would suffer losses in yields and output, while the Highlands would benefit.
- Accounting for adaptation implies that output drops (increases) less: over-estimation would be between 1-3 pp annually in the Coast.

Robustness

1. Alternative specifications
2. Alternative time measures
3. Alternative thresholds (e.g. thresholds by region, maximum R2)
4. Use the share of hot days instead of HDD

Conclusion

- We find that household farms engage in adaptive behavior in production in the presence of extreme heat: input use
- Farmers that can smooth consumption in other ways avoid this response
- Increasing land attenuates the drop in current output, but may affect future land productivity
- How sustainable is this practice in the long run? We cannot tell.
- However, accounting for regional heterogeneity and adaptation matter quantitatively for climate change predictions.

Main Results - Adaptation in Production

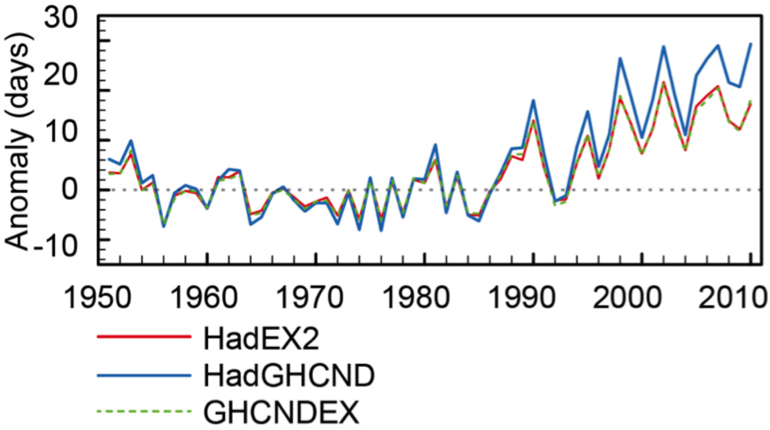
Using % of days above the threshold

	Y/T	TFP		Y	T
Dep var:	ln(output/ha) (1)	ln(output) (2)	ln(output) (3)	ln(output) (4)	ln(land used) (5)
Days with Harmful Degrees (%)	-0.009*** (0.003)	-0.008*** (0.003)	-0.009*** (0.003)	-0.007** (0.003)	0.002* (0.001)
Input controls	No	OLS	IV	No	No
N	54,981	54,972	54,972	54,981	54,981
R2	0.241	0.405	0.390	0.244	0.313

Additional Tables: Alternative specifications

	Y/T	TFP	Y	T	L^{hired}
Dep var:	ln(output/ha)	ln(output)	ln(output)	ln(land used)	ln(wage bill)
	(1)	(2)	(3)	(4)	(5)
1. Adding endowment and additional FE	-0.166**	-0.140**	-0.136**	0.025*	-0.130
	(0.065)	(0.058)	(0.069)	(0.014)	(0.084)
2. Clustering s.e. by province (n=159)	-0.192**	-0.164**	-0.157*	0.031*	-0.149*
	(0.074)	(0.063)	(0.084)	(0.016)	(0.090)
3. Dropping sample October-March	-0.152*	-0.128	-0.109	0.042**	-0.061
	(0.085)	(0.079)	(0.092)	(0.021)	(0.082)
4. Common HDD threshold at 32C	-0.128***	-0.112***	-0.103**	0.022**	-0.082
	(0.040)	(0.037)	(0.044)	(0.010)	(0.050)
5. Region-specific HDD threshold (32C and 36C)	-0.156***	-0.135***	-0.133**	0.019*	-0.117**
	(0.050)	(0.046)	(0.055)	(0.011)	(0.059)
6. Exposure to temperature in the last 12 months	-0.230**	-0.205**	-0.151	0.069**	-0.098
	(0.115)	(0.101)	(0.123)	(0.027)	(0.155)
Input controls	No	Yes	No	No	No

Warm days anomaly



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