Weather and Death in India

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Weather and Death: Research Questions

1. Does the weather affect mortality in developing countries?
   (a) Are these effects different across rural and urban regions?
   (b) Why do these effects exist?
2. Can these effects be mitigated? (In progress. Not for today.)
3. What do these effects imply for policy (and the health costs of climate change)?

Motivation

- Large rural populations still rely on weather-dependent agriculture:
  - Limited access to 'coping' technologies (irrigation, AC, etc).
  - Famines have largely been avoided. But nutrition and health literatures suggest that weather shocks may still affect mortality. How much?
- Extensive literature on (impressive) consumption smoothing via risk-sharing arrangements within villages:
  - But what happens to risk posed by aggregate shocks?
- Climate change costs and benefits:
  - Size of health risks poorly understood, especially in LDCs were they are likely to be largest.

This Paper

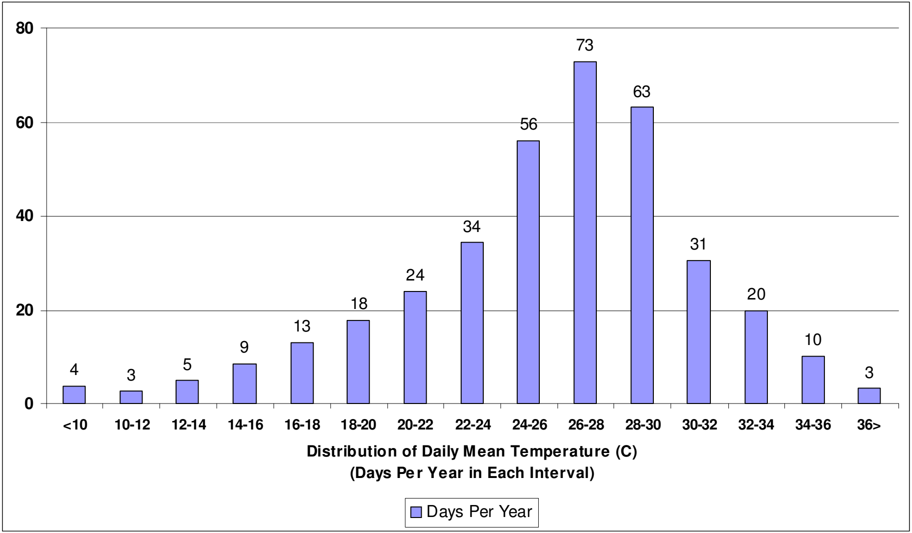
- Estimate ('semi-parametric') relationship between daily district-level ($N \cong 300$) weather and annual mortality rate in India.
  - Contrast rural/urban effects given that rural incomes are much more weather-dependent.

- Estimate effects of weather on rural real income (agricultural output, wages, and prices) and urban real income (manufacturing output, wage, price index, etc).

- Implications of results for predicted costs of climate change.

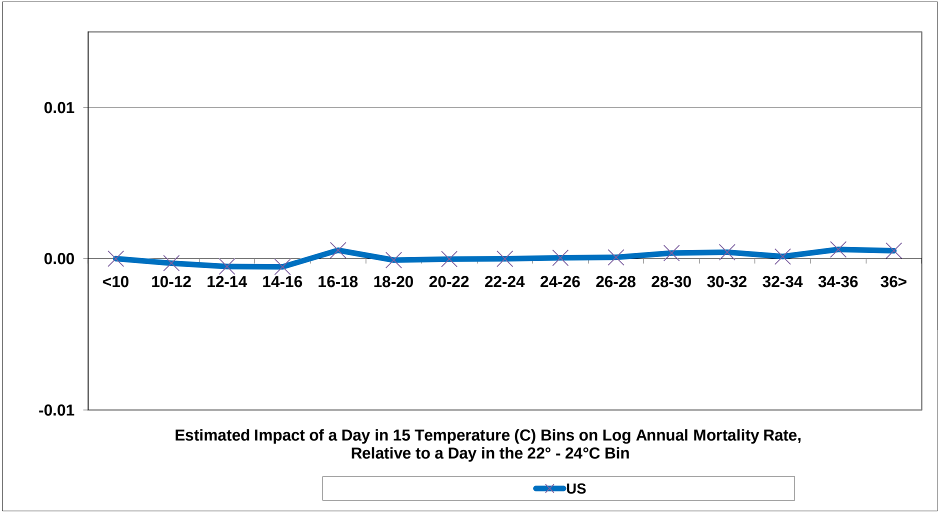
Daily Temperatures in India: 1957-2000

Using our data we can construct one of these histograms per district and year



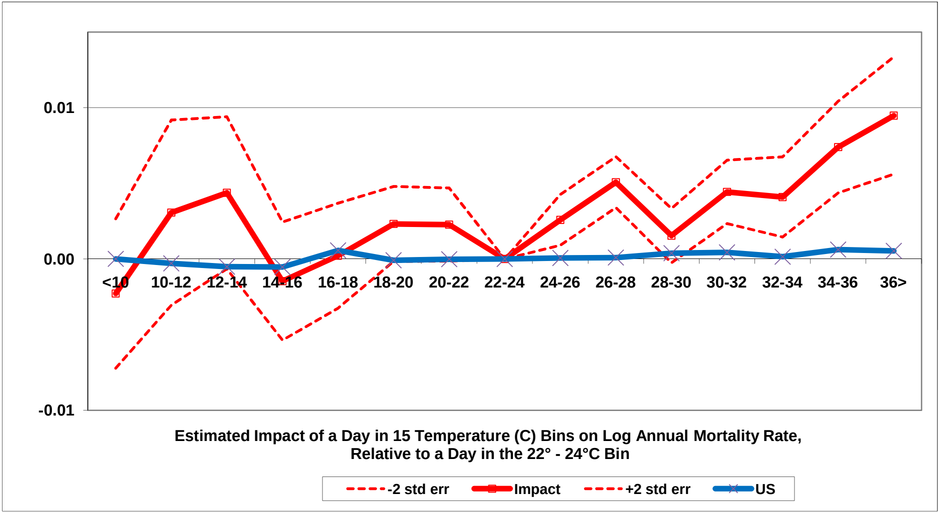
Weather and Death in the US and India

Estimates for US from Deschenes and Greenstone (2009)



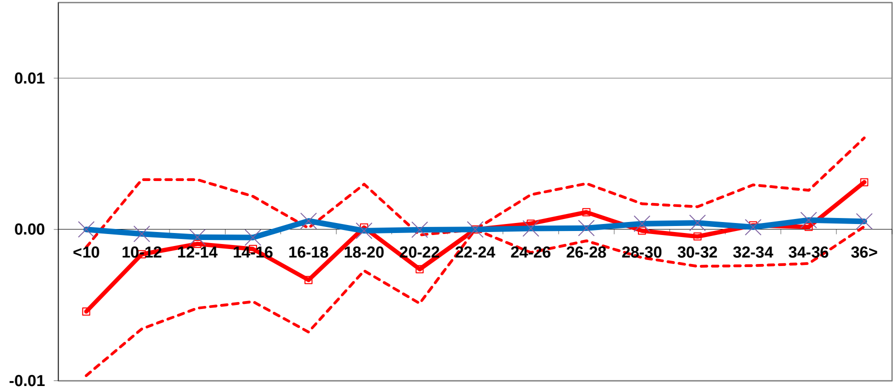
Weather and Death in the US and India

US and Total India



Weather and Death in the US and India

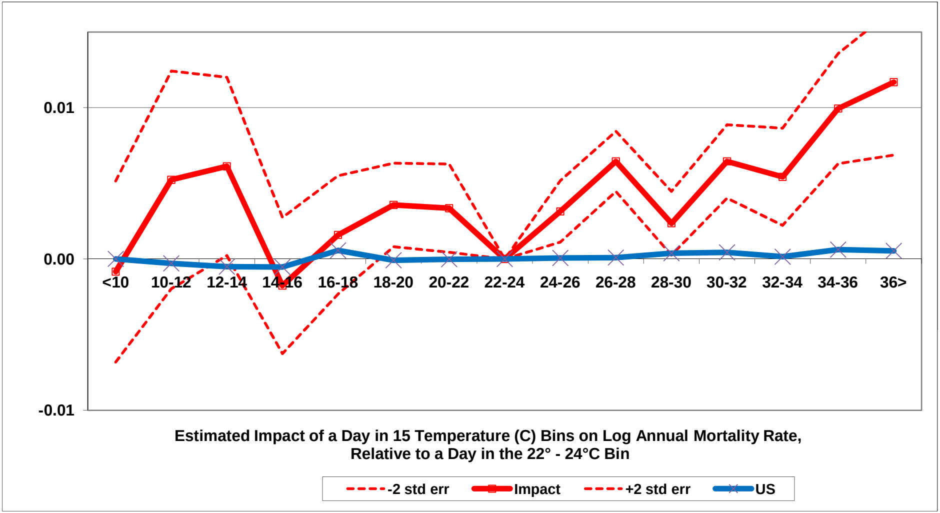
US and Urban India



Estimated Impact of a Day in 15 Temperature (C) Bins on Log Annual Mortality Rate, Relative to a Day in the 22° - 24°C Bin

Weather and Death in the US and India

US and Rural India: Indian point estimates 20× larger than in US



Summary of Results

1. Rural incomes (productivity, nominal wages and prices) all mirror Rural death response (ie large effects).
2. Urban incomes (productivity, nominal wages and prices) all mirror Urban death response (ie no effects).
3. Bank deposits: Fall in rural areas; no change in urban areas
4. Mortality:
    - Effects in rural areas. No effects in urban areas.
    - Not even urban effects on infants.
    - Within rural, no effects during non-growing season (hottest time of the year).

Outline of Talk

Background

Data and Empirical Strategy

Results:
- Productivity
- Nominal wages
- Prices
- Bank Deposits
- Mortality

Implications of Climate Change

Conclusion

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Context: India, 1956-2000

- Extremely poor, and poor health:
  - 35% lived on less than $1 per day in 1983.
  - Crude death rate (1983): 8 per 1000
  - Infant death rate (1983): 40 per 1000

- Rural vs Urban:
  - 75% of population lives in ‘rural’ sector (settlement pop $<$ 5,000)
  - Poorer: 39% in poverty (R) vs 23% (U).
  - Far higher dependence on agriculture for income.
  - Higher expenditure shares on food.

- Agriculture:
  - 60% of nation-wide employment (over 80% in rural areas).
  - Still largely rain-fed.

Weather and Death: Two Hypotheses

1. Income based effect:
   - Rainfall and temperature extremes damage plants/livestock and hence rural incomes.
   - Deschenes and Greenstone (2007) on US, Guiteras (2009) on India.
   - Income shock likely to affect consumption if 'aggregate' shock.
   - Consumption shock can lead to death, this year or next. ('Synergies' hypothesis: malnutrition can have strong weakening effect, dramatically increasing exposure to disease.)

2. Non-income based effect: weather extremes kill humans directly.

Income Based Mortality: Predictions

- Consequences of extreme weather during the growing season for observables:
  - Lower agricultural yields.
  - $\Rightarrow$ Higher agricultural prices (if markets imperfectly integrated)
  - $\Rightarrow$ Lower real incomes in R but not U.
  - $\Rightarrow$ Lower bank deposits in R but not U.
  - $\Rightarrow$ Lower consumption levels (if incomplete credit markets and insurance) in R but not U. (Not observed!)
  - $\Rightarrow$ More death due to malnutrition (directly or through weakened immune system) in R but not U. (But death by cause or direct 'weather deaths' not observed.)

- Extreme weather in the non-growing season has no effect on death in R or U.

Non-Income-Based Mortality Effects

- Heat stress (cardiovascular):
  - Survey: Basu and Smet (2003).
  - Hajat et al (2005): small effects in Delhi (around one heat wave).
  - Deschenes-Moretti (2009): small effects in the US, largely offset by 'harvesting'.
- Change in disease environment:
  - Malaria thrives in hot and wet conditions, but malaria rarely fatal in India.
  - Intestinal infections and deaths peak when it's wet (Dyson, 1991; Matlab studies; Chambers et al (eds) 1981).
- Both effects likely to operate in both urban and rural areas, and in both growing and non-growing seasons.

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Data Sources

- Historical Weather:
  - Precipitation: daily precipitation at each 1 × 1 degree lat/long gridpoint, from Indian Meteorological Department. Spatial interpolations based on over 7,000 underlying stations.
  - Temperature: modeled daily precipitation at each 1 × 1 gridpoint, from National Center for Atmospheric Research.
  - Gridpoints mapped to districts by inverse-distance weighting (within 100 km radius).
- Mortality Rates:
  - *Vital Statistics of India* (VSI), 1956-2000.
  - Universe of registered deaths. But under-registration problematic.

Data Sources

- Economic outcomes:
  - Agricultural outcomes (yields, prices, wages), 1956-86, from World Bank Agriculture and Climate Database.
  - Urban wages and output, 1965-1990, relate to state-level registered manufacturing at state-level, from ASI via Ozler, Datt and Ravallion (1996).
  - Urban price index 1965-1990, CPI for Industrial Workers, at state-level, from NSS via Ozler, Datt and Ravallion (1996)
  - Bank deposits in registered banks, 1970-1998, from Reserve Bank of India.

Empirical approach: Graphical

- To construct 'flexible' temperature impact graphs, estimate regressions of following form and plot the 15 $\widehat{\theta}$'s (best seen graphically):

$$\ln Y_{dt} = \sum_{j=1}^{15} \theta_j T_{dt}^j \; + \; \delta \text{RAIN Controls}_{dt}$$

$$+ \; \alpha_d + \beta_t + \gamma_r^1 t + \gamma_r^2 t^2 + \varepsilon_{dt}$$

  - dt: unit of observation is a district×rural/urban area, observed annually
  - Y_{dt}: various outcome variables.
  - T_{dt}^j: Number of days in dt in which daily mean temperature was in 'bin' j
  - RAIN_{dt}: Various controls for precipitation

Empirical approach: Graphical

$\ln Y_{dt} = \sum_{j=1}^{15} \theta_j T_{dt}^j + \delta \text{RAIN Controls}_{dt} + \alpha_d + \beta_t + \gamma_r^1 t + \gamma_r^2 t^2 + \varepsilon_{dt}$

- Intuition for these functional forms:
  - Temperature is not storable, so total annual impact is approximated by sum of each day's impact (with unknown lags).
  - Water is much more storable, so appropriate measures will aggregate over many days.
- Other adjustments:
  - Weight by population
  - Cluster at district level

Empirical approach: Tables

- For tables, also estimate more parsimonious, parametric specifications:

$$
\begin{aligned}
Y_{dt} &= \theta \mathrm{CDD32}_{dt} + \sum_{k=1}^{3} \delta_k \mathbf{1}\left\{\mathrm{RAIN}_{dt} \text{in tercile } k\right\} \\
&+ \alpha_d + \beta_t + \gamma_r^1 t + \gamma_r^2 t^2 + \varepsilon_{dt}
\end{aligned}
$$

- $\mathrm{CDD32}_{dt}$: Cumulative number of degrees (above 32° C)-times-days in year t
  - Collapses 'flexible approach' (15 $\widehat{\theta}$'s) into a spline.
  - Common approach in public health and agronomy: humans and plants tend to cope well until temperatures exceed 32° C.

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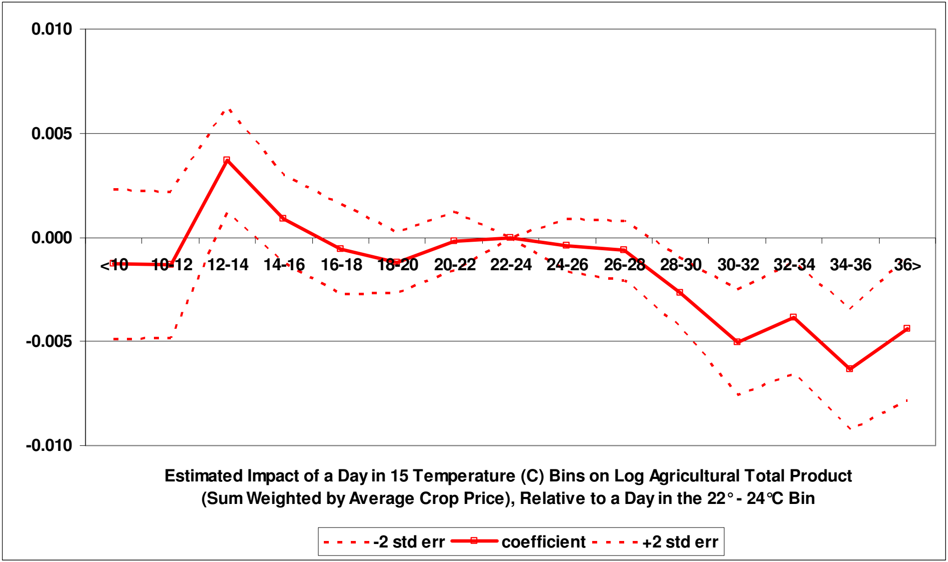
Temperature and Productivity: Rural

Rural Productivity: Real aggregate agricultural output per acre



Weather and Productivity: R vs U

Rural: real agricultural output per acre;
Urban: (state-level) registered manufacturing output

Dependent variable: log (productivity)	Rural	Urban
	(1)	(2)
Temperature (degree-days over 32C) ÷ 10	-0.0100	-0.0000
	(0.0035)***	(0.0055)
Rainfall in lower tercile	-0.0915	-0.0435
	(0.0097)***	(0.0327)
Rainfall in upper tercile	0.0036	-0.0595
	(0.0063)	(0.0414)
Observations	7,729	512

Notes: Regressions include district fixed effects, year fixed effects and climatological region-specific quadratic time trends. Regressions weighted by average cultivated area. Standard errors clustered by district.

Weather and Productivity: GS vs NGS

Rural only. Real agricultural output per acre

Dependent variable: log (productivity)	(1)	(2)
GROWING SEASON [Jun-Dec]:		
Temperature (degree-days over 32C) ÷ 10	-0.0090 (0.0031)***	-0.0089 (0.0031)***
Rainfall in lower tercile	-0.0913 (0.0092)***	-0.0918 (0.0094)***
Rainfall in upper tercile	0.0016 (0.0066)	0.0016 (0.0066)
NON-GROWING SEASON [Mar-May]:		
Temperature (degree-days over 32C) ÷ 10		0.0015 (0.0022)
Rainfall in lower tercile		-0.0193 (0.0067)**
Rainfall in upper tercile		-0.0016 (0.0071)

Notes: Regressions include district fixed effects, year fixed effects and climatological region-specific quadratic time trends. Regressions weighted by average cultivated area. Standard errors clustered by district.

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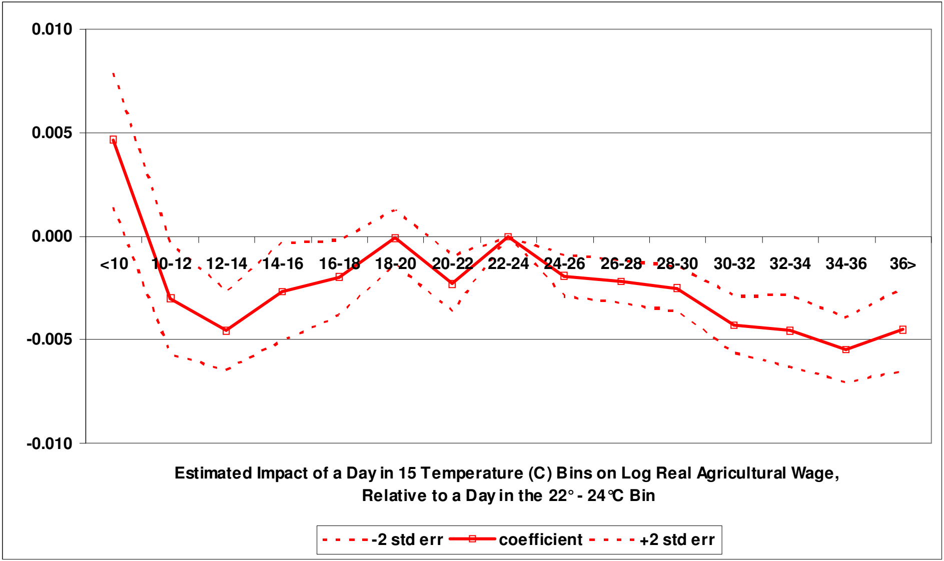
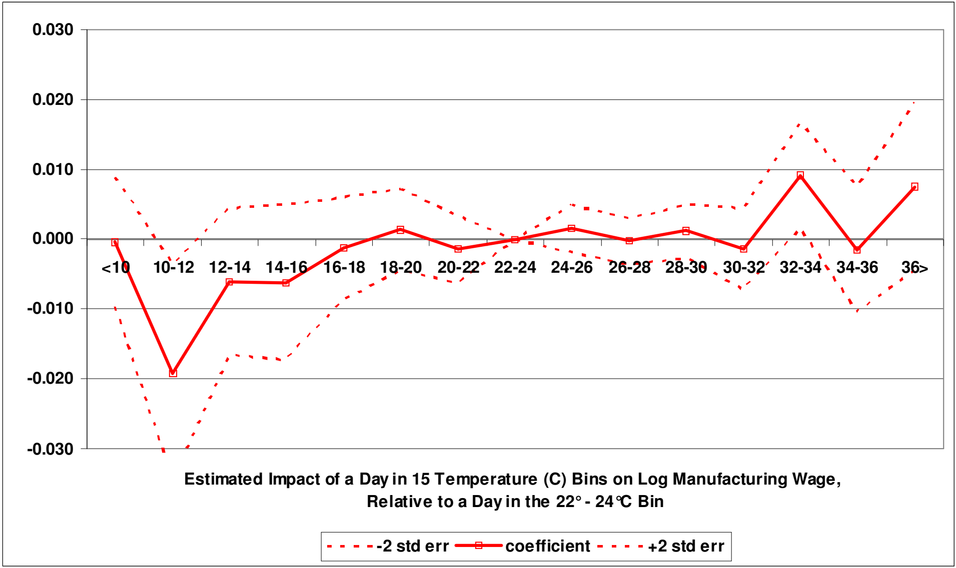
Temperature and Nominal Wages: Rural

Rural Wage: District-level agricultural wage



Temperature and Nominal Wages: Urban

Urban Wage: State-level earnings per worker in manufacturing sector



Weather and Nominal Wages: R vs U

Rural: Agricultural wages;
Urban: State-level manufacturing earnings per worker

Dependent variable: log (nominal wage)	Rural	Urban
	(1)	(2)
Temperature (degree-days over 32C) ÷ 10	-0.0045	0.0065
	(0.0015)***	(0.0057)
Rainfall in lower tercile	-0.0167	-0.0223
	(0.0066)**	(0.0647)
Rainfall in upper tercile	0.0050	-0.0105
	(0.0069)	(0.0746)
Observations	7,994	482

Notes: Regressions include district fixed effects, year fixed effects and climatological region-specific quadratic time trends. Regressions weighted by population. Standard errors clustered by district.

Weather and Nominal Wages: GS vs NGS

Rural only. Nominal agricultural wage

Dependent variable: log (nominal wage)	(1)	(2)
GROWING SEASON [Jun-Dec]:		
Temperature (degree-days over 32C) ÷ 10	-0.0041	-0.0043
	(0.0015)**	(0.0015)**
Rainfall in lower tercile	-0.0167	-0.0175
	(0.0066)**	(0.0065)**
Rainfall in upper tercile	0.0050	0.0050
	(0.0069)	(0.0069)
NON-GROWING SEASON [Mar-May]:		
Temperature (degree-days over 32C) ÷ 10		0.0014
		(0.0014)
Rainfall in lower tercile		-0.0063
		(0.0064)
Rainfall in upper tercile		-0.0107
		(0.0069)

Notes: Regressions include district fixed effects, year fixed effects and climatological region-specific quadratic time trends. Regressions weighted by population. Standard errors clustered by district.

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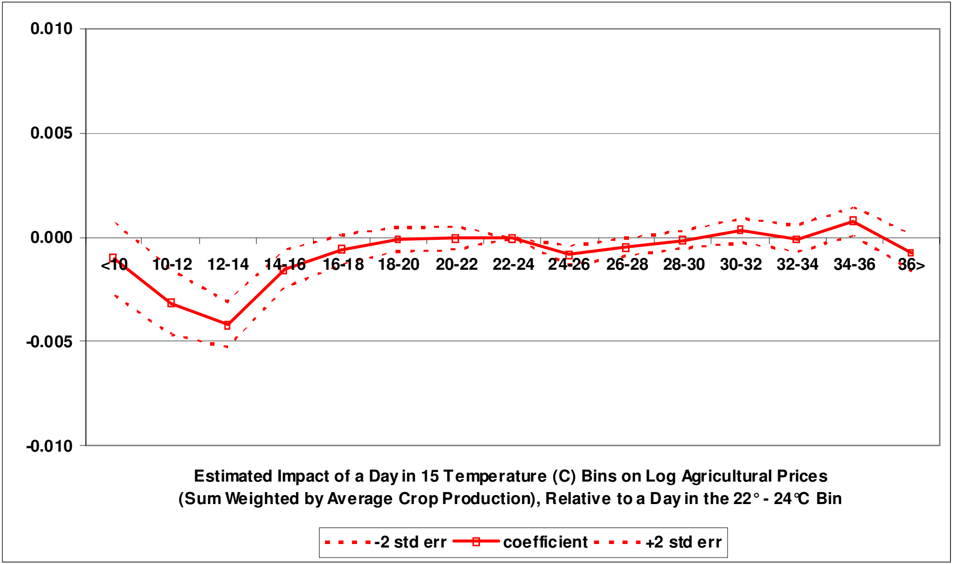
Temperature and Prices: Rural

Rural Prices: Price index of agricultural prices



Weather and Prices: R vs U

Rural: Agricultural prices (mostly 'farm gate');
Urban: state-level industrial workers' CPI

Dependent variable: log (prices)	Rural	Urban
	(1)	(2)
Temperature (degree-days over 32C) ÷ 10	0.0019	0.0014
	(0.0007)**	(0.0094)
Rainfall in lower tercile	0.0107	0.0108
	(0.0029)***	(0.0066)
Rainfall in upper tercile	0.0014	0.0035
	(0.0029)	(0.0051)
Observations	7,994	592

Notes: Regressions include district fixed effects, year fixed effects and climatological region-specific quadratic time trends. Regressions weighted by population. Standard errors clustered by district.

Weather and Prices: GS vs NGS

Rural only. Agricultural prices (mostly 'farm gate')

Dependent variable: log (prices)	(1)	(2)
GROWING SEASON [Jun-Dec]:		
Temperature (degree-days over 32C) ÷ 10	0.0019	0.0020
	(0.0007)**	(0.0008)***
Rainfall in lower tercile	0.0107	0.0111
	(0.0029)***	(0.0029)***
Rainfall in upper tercile	0.0014	0.0014
	(0.0029)	(0.0029)
NON-GROWING SEASON [Mar-May]:		
Temperature (degree-days over 32C) ÷ 10		-0.0010
		(0.0006)
Rainfall in lower tercile		0.0077
		(0.0025)***
Rainfall in upper tercile		0.0042
		(0.0027)

Notes: Regressions include district fixed effects, year fixed effects and climatological region-specific quadratic time trends. Regressions weighted by population. Standard errors clustered by district.

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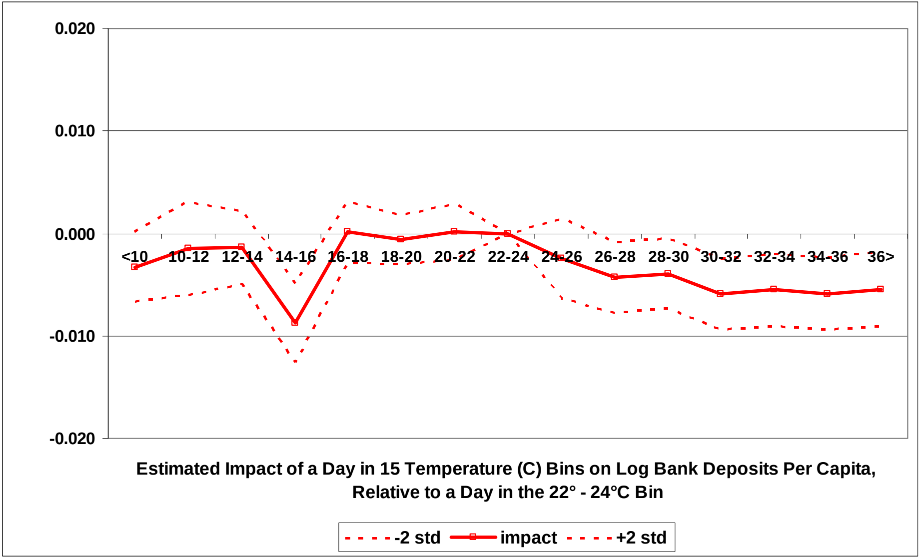
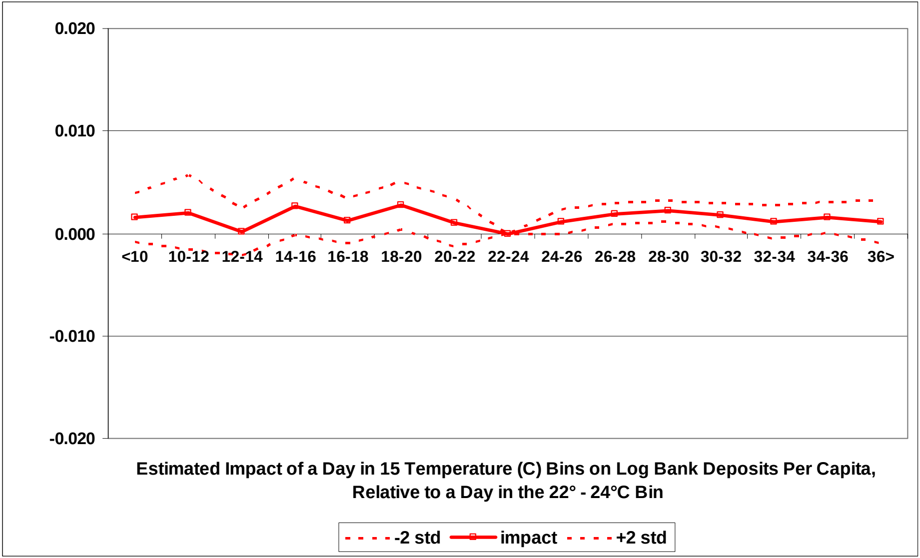
Temperature and Bank Deposits: Rural

Bank deposits per capita in Rural areas



Temperature and Bank Deposits: Urban

Bank deposits per capita in Urban areas



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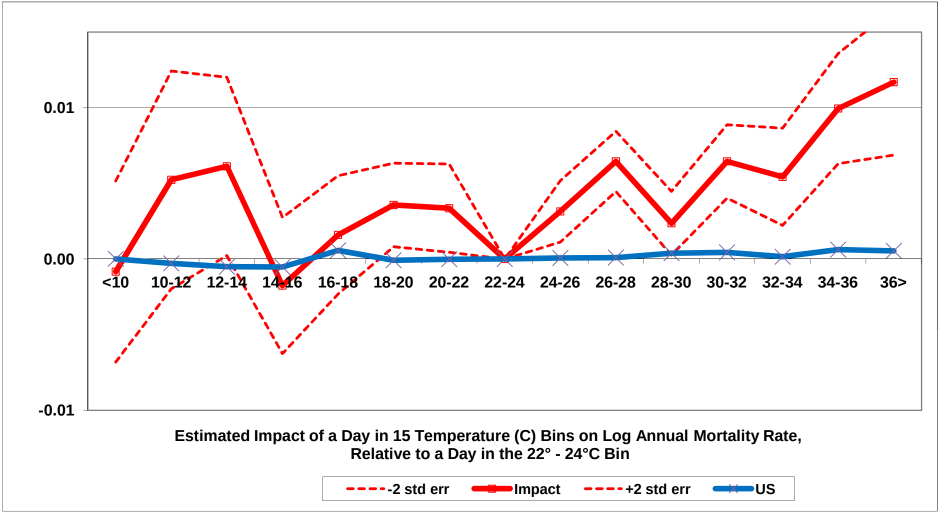
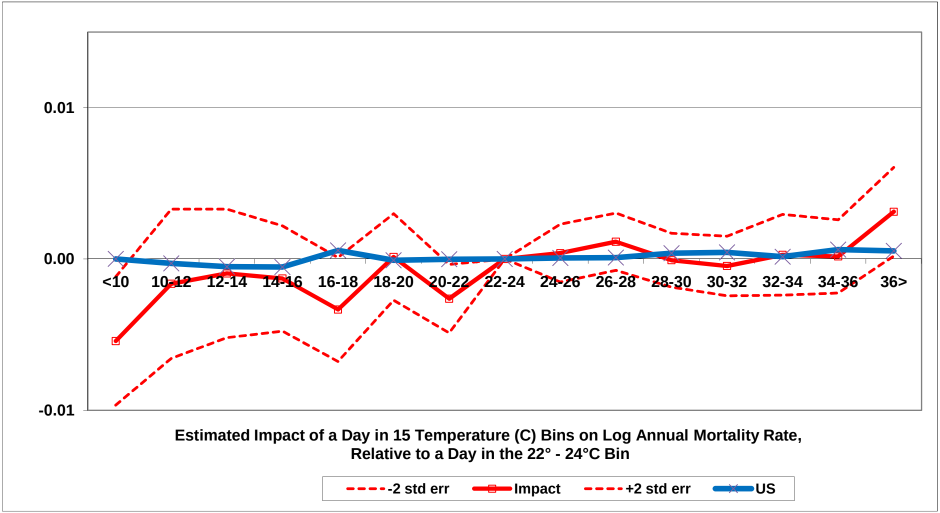
Weather and Death in the US and India

US and Rural India: Indian point estimates 20× larger than in US



Weather and Death in the US and India

US and Urban India



Weather and Mortality: R vs U

Crude death rate (deaths per 1,000 population at mid-year)

Dependent variable: log (total mortality rate)	Rural	Urban
	(1)	(2)
Temperature (degree-days over 32C) ÷ 10	0.0134	0.0045
	(0.0032)***	(0.0020)**
Rainfall in lower tercile	0.0318	-0.0030
	(0.0145)**	(0.0105)
Rainfall in upper tercile	-0.0003	-0.0148
	(0.0184)	(0.0110)
Observations	11,121	11,525

Notes: Regressions include district fixed effects, year fixed effects and climatological region-specific quadratic time trends. Regressions weighted by population. Standard errors clustered by district.

Weather and Mortality: GS vs NGS

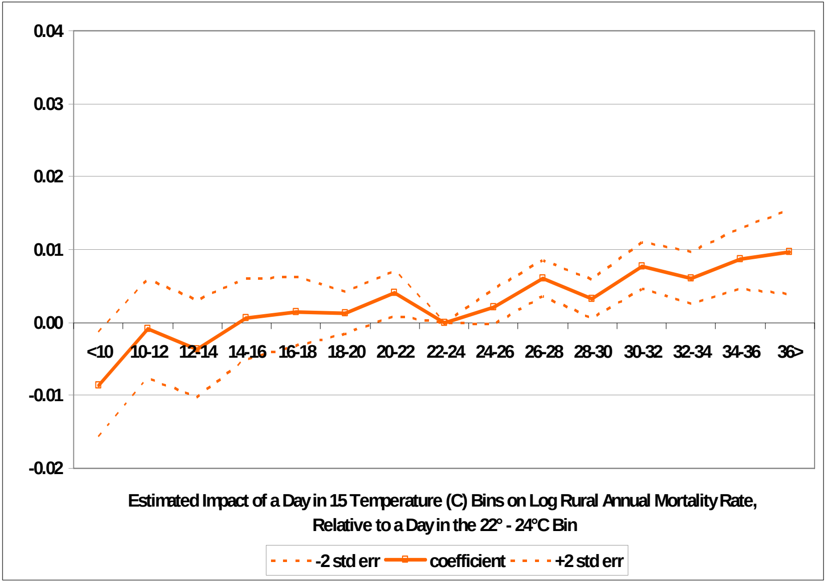
Rural only. Crude death rate (deaths per 1,000 population at mid-year)

Dependent variable: log (total mortality rate)	(1)	(2)
GROWING SEASON [Jun-Dec]:		
Temperature (degree-days over 32C) ÷ 10	0.0207	0.0243
	(0.0050)***	(0.0049)***
Rainfall in lower tercile	0.0300	0.0201
	(0.0168)*	(0.0169)
Rainfall in upper tercile	0.0104	0.0089
	(0.0166)	(0.0169)
NON-GROWING SEASON [Mar-May]:		
Temperature (degree-days over 32C) ÷ 10		0.0057
		(0.0049)
Rainfall in lower tercile		0.0455
		(0.0143)***
Rainfall in upper tercile		0.0099
		(0.0134)

Notes: Regressions include district fixed effects, year fixed effects and climatological region-specific quadratic time trends. Regressions weighted by population. Standard errors clustered by district.

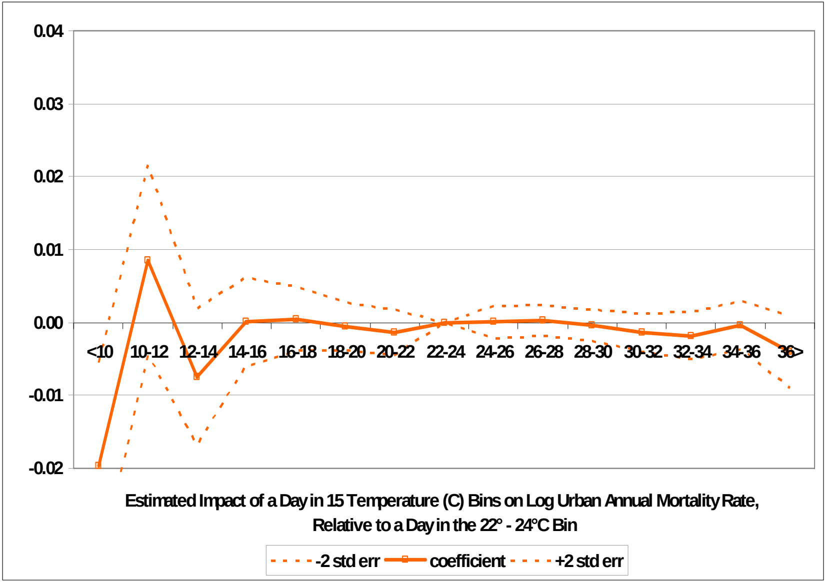
Temperature and Infant Mortality: Rural

Rural infant mortality: mortality rate under age of 1



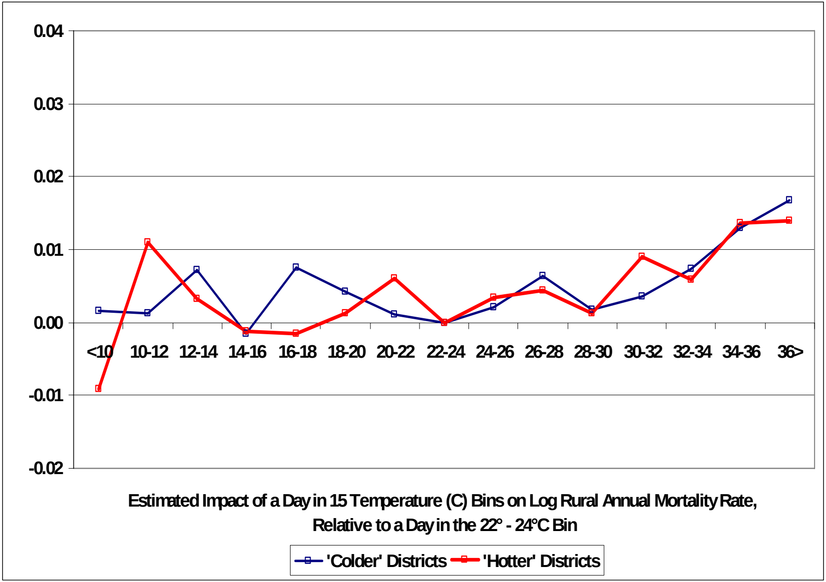
Temperature and Infant Mortality: Urban

Urban infant mortality: mortality rate under age of 1



Temperature and Mortality: Adaptation?

Rural total mortality, districts split into 'hot' and 'cold' by median cutoff



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Implications of Climate Change I

- We have documented a large reduced-form impact of both temperature and rainfall extremes on mortality in India from 1956-2000
- Looking into the future: As India's climate changes throughout the 21st Century, what are the implications for mortality?
  - Clearly one has to be very skeptical of the use of reduced-form estimates based on the past to predict the future.
  - Under most scenarios, our estimates (based on short-lived shocks) will place an upper-bound on the effects of a long-run change.

Implications of Climate Change II

- Climatological models predict ΔT_d (and ΔRAIN_d, though these are more controversial)

- We use our earlier estimates of the mortality consequences of weather variation to estimate the mortality consequences of predicted ΔT_d:

$$\widehat{\Delta Y_d} = \sum_j \widehat{\theta}_j \Delta T_d^j + \sum_{k=1}^{3} \widehat{\delta}_k \Delta \mathbf{1}\left\{\text{RAIN}_d \text{in tercile } k\right\}$$

- Report pop-weighted average of these district-level impacts.

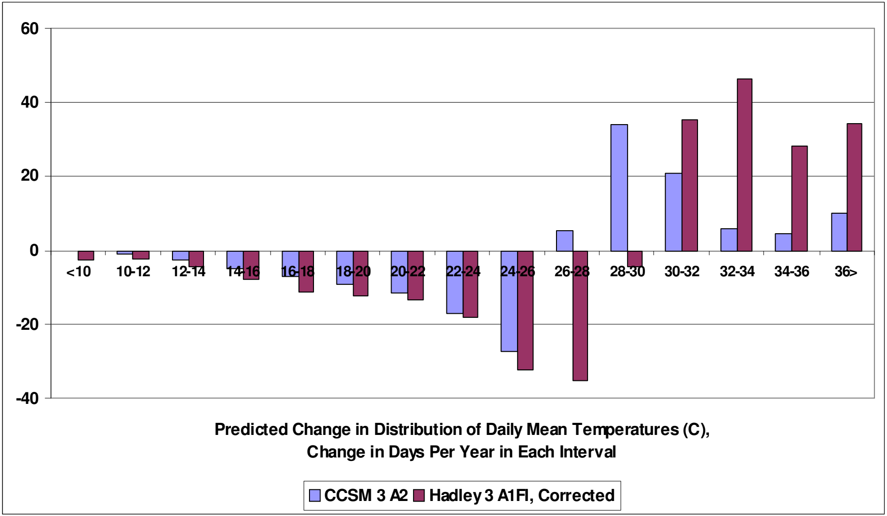
Implications of Climate Change III

- Feed in 2 standard C.C. models:
  1. Hadley Centre's 3 A1F1 (corrected) model and NCAR's CCSM 3 A2 model

  - Both are 'business as usual' scenarios (no CO_2 mitigation)
  - Both do not include 'catastrophic scenarios' (Himalayan glaciers melt, monsoon terminates, sea level rises, more cyclones)

- Details:
  - Models simulate full daily time path of temp. and rain from 1990-2099
  - Different time paths for each district in India
  - Define $\Delta T_d \equiv T_d^{2070-2099} - T_d^{1957-2001}$ etc
  - Compute $\widehat{\Delta Y_d}$ for each district d and take population-weighted average

Predicted Change in Temp. Distribution



Climate Change and Mortality

Percentage impacts: $\widehat{\Delta Y_d} = \sum_j \widehat{\theta}_j \Delta T_d^j + \sum_{k=1}^3 \widehat{\delta}_k \Delta \mathbf{1}\{\text{RAIN}_d \text{in tercile } k\}$ in 2070-2099 (on average)

	Impact of Change in Days with Temperature:			Total Temperature Impact	Temperature and Precipitation Impacts
	< 16 C	16 C-32 C	> 32 C		
	(1a)	(1b)	(1c)	(2)	(3)
Based on Hadley 3, A1F1					
Pooled	-0.010	-0.139	0.659	0.510	0.462
	(0.030)	(0.045)	(0.126)	(0.125)	(0.142)
Rural Areas	-0.030	-0.164	0.853	0.658	0.617
	(0.039)	(0.055)	(0.153)	(0.126)	(0.173)
Urban Areas	0.036	0.013	0.090	0.112	0.116
	(0.033)	(0.058)	(0.105)	(0.101)	(0.116)
Based on CCSM3, A2					
Pooled	-0.010	0.039	0.145	0.176	0.116
	(0.013)	(0.042)	(0.028)	(0.061)	(0.084)
Rural Areas	-0.015	0.071	0.189	0.245	0.207
	(0.016)	(0.049)	(0.035)	(0.074)	(0.099)
Urban Areas	0.009	0.016	0.028	0.052	-0.078
	(0.013)	(0.042)	(0.022)	(0.054)	(0.092)

Climate Change and Mortality

Percentage impacts: $\widehat{\Delta Y_d} = \sum_j \widehat{\theta}_j \Delta T_d^j + \sum_{k=1}^{3} \widehat{\delta}_k \Delta \mathbf{1}\{\text{RAIN}_d \text{in tercile } k\}$

All India

	Impact of Change in Days with Temperature:			Total Temperature Impact	Temperature and Precipitation Impacts
	< 16 C (1a)	16 C-32 C (1b)	> 32 C (1c)	(2)	(3)
Based on Hadley 3, A1F1					
2010-2039	-0.009	0.027	0.057	0.075	0.037
	(0.014)	(0.026)	(0.012)	(0.039)	(0.054)
2040-2069	-0.011	-0.013	0.270	0.246	0.205
	(0.025)	(0.028)	(0.050)	(0.069)	(0.086)
2070-2099	-0.010	-0.139	0.659	0.510	0.462
	(0.030)	(0.045)	(0.126)	(0.125)	(0.142)
Based on CCSM3, A2					
2010-2039	-0.006	0.082	-0.073	0.003	-0.054
	(0.010)	(0.016)	(0.015)	(0.018)	(0.041)
2040-2069	-0.008	0.097	0.002	0.091	0.031
	(0.006)	(0.023)	(0.005)	(0.023)	(0.050)
2070-2099	-0.008	0.039	0.145	0.176	0.116
	(0.013)	(0.042)	(0.028)	(0.061)	(0.084)

Outline of Talk

Background

Data and Empirical Strategy

Results:

- Productivity
- Nominal wages
- Prices
- Bank Deposits
- Mortality

Implications of Climate Change

Conclusion

Summary

- Both temperature and rainfall extremes play a large (and unappreciated) role in the health lives of India's rural poor:
  - One SD more degree-days (over 32 C) leads to 9 % higher crude death rate.
  - Temperature: 20 $\times$ larger effect than in USA.
  - Cluster of findings consistent with these effects working through agricultural income.
- Implications:
  - Smoothing of marginal utility in rural India seems far from complete.
  - Weather-dependent income transfers are likely to save lives cheaply.
  - Standard global warming scenarios imply dire upper-bound (limited adaptation) consequences.