Weather and Death in India:

Mechanisms and Implications of Climate Change

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Weather and Health: Empirical Questions

1. How large are the effects of weather shocks on health in developing countries?
2. Why are there effects?
3. What do these effects imply for policy?

Weather and Health: Motivation

- Rural LDC citizens seem potentially exposed to weather shocks (incomes, prices).
    - Does this exposure matter?
- How complete is marginal utility smoothing?
    - Intra-village consumption smoothing seems strong.
    - But do aggregate shocks matter?
- Climate change costs and benefits:
    - Size of health risks not yet understood.
- Democracies seem to avoid famine (Sen).
    - But are there 'sub-famine' effects of weather on death?

Approach of This Paper

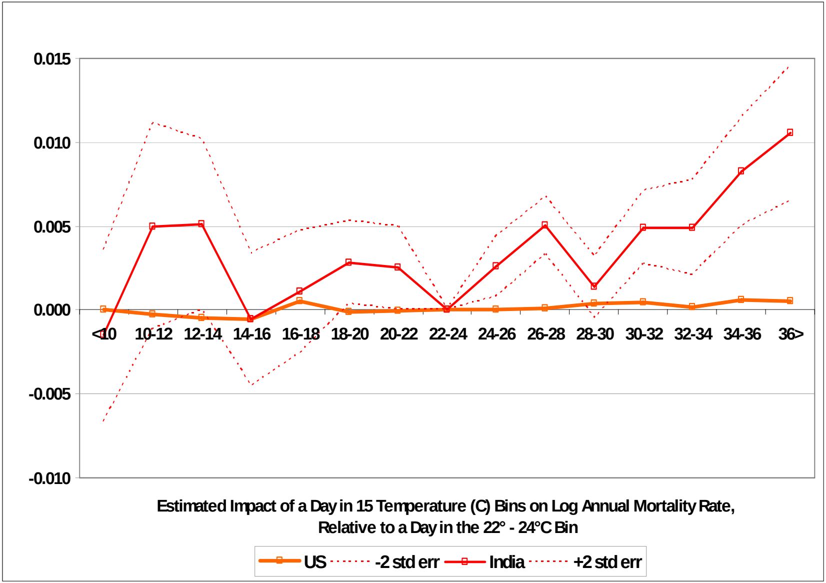
- Estimate effect of 'weather' (temperature and precipitation) variation on the mortality rate.
  - Panel of Indian districts, from 1956-2000.
  - Exploit (presumably) random nature of weather shocks.
  - Daily weather data is central to our approach.
- Compare competing predictions from 2 different mechanisms relating weather to death:

  1. 'Income': income falls $\Rightarrow$ consumption falls $\Rightarrow$ mortality risk rises
  2. 'Non-income': heat stress, disease, dehydration

- Implications for policy:
  - What would an income support policy cost?
  - Upper bound costs of predicted climate change

Summary of Results I: India vs. USA

India: 1° C rise in average annual temperature increases the mortality rate by 10%



Summary of Results II

- Cluster of findings consistent with an income-based temperature-death relationship:
  - No effect in urban India (not even on infants)
  - Within rural India, no effect in the non-growing season
  - Rural incomes: Agricultural yields fall, agricultural wages fall, agricultural prices rise.
  - Urban incomes: Manufacturing wages do not change, urban prices don't change.
  - Bank deposits: Fall in rural areas; no change in urban areas
- Rainfall-death relationship seems more nuanced.

Outline of Talk

Background and Predictionns

Reduced-Form Results: Weather and Death

Mechanisms: ‘Income’ vs ‘Non-income’ Effects

Implications for Policy

Conclusion

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Income-Based Mortality Effect

- Rainfall <u>and</u> temperature extremes damage plants and hence rural incomes.
  - Deschenes and Greenstone (2007) and Schlenker (2009) on United States.
- Could rural income shocks pass through into consumption?
  - Evidence for inter-seasonal variation in consumption and nutrition (Matlab studies).
  - A key question is whether income shocks are ‘aggregate’ or ‘idiosyncratic’ (Morduch, 1992).
- Could consumption shortfalls lead to death?
  - ‘Synergies’ hypothesis (eg Scrimshaw, Pelletier): malnutrition can have strong weakening effect, dramatically increasing exposure to disease.

Income-Based Mortality Effect: Predictions

- Consequences of extreme weather during the growing season for observables:
  - Lower agricultural yields
  - Higher agricultural prices
  - Lower real incomes in R but not U
  - Lower bank deposits in R but not U
  - Lower consumption levels (if incomplete credit markets and insurance) in R but not U
  - More death due to malnutrition in R but not U

- Extreme weather in the non-growing season has no effect (on Y, p, w, or death) in R or U

Non-Income-Based Mortality Effect

- Heat stress (cardiovascular):
  - e.g. 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'.
  - Cause of low birth-weight (Wells et al, 2002).
- Change in disease environment:
  - Malaria thrives in hot and wet conditions, but malaria rarely fatal in India
  - Intestinal infections and deaths peak in rainy season (Dyson, 1991; Matlab studies; Chambers et al (eds) 1981)

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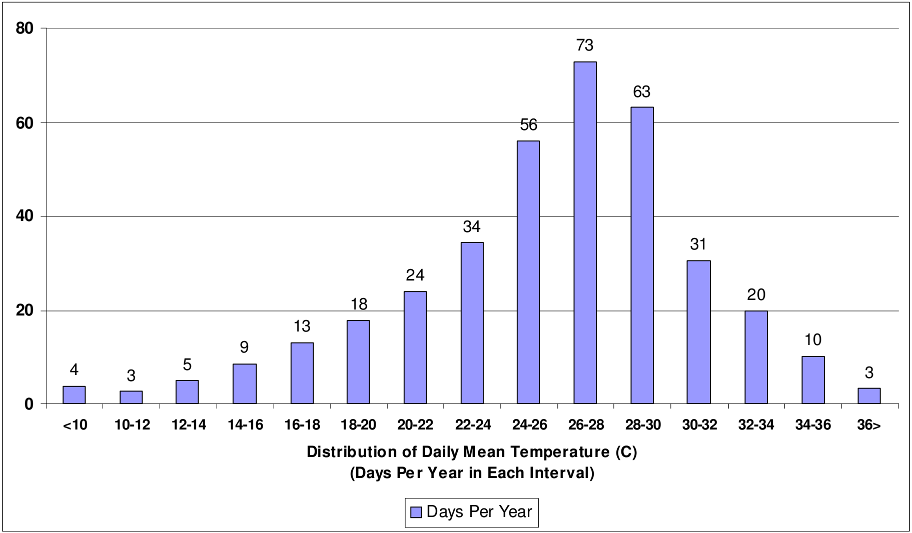
Data Sources

- Mortality Rates:
  - *Vital Statistics of India* (VSI), 1957-2001
  - Universe of registered deaths
  - Check results against DHS maternal histories data
  - And future work: SRS data
- Historical Weather:
  - High-resolution modeled daily weather at each 1×1 degree lat/long gridpoint
  - Source: National Center for Atmospheric Research (US Government)
  - Gridpoints mapped to districts by inverse-distance weighting (within 100 km radius)

Daily Temperatures in India: 1957-2000



Empirical approach I

- Estimate regressions of following form:

$$
\begin{aligned}
Y_{dt} = \sum_{j=1}^{15} \theta_j T_{dt}^j \; & + \; \delta^K P_{dt}^{Kharif} + \delta^R P_{dt}^{Rabi} \\
& + \; \alpha_d + \beta_t + \{\gamma_r t^3\} + \varepsilon_{dt}
\end{aligned}
$$

- dt: unit of observation is a district$\times$rural/urban area, observed annually
- Y_{dt}: log of annual death rate (deaths per 1,000)
- T_{dt}^j: Number of days in dt in which daily mean temperature was in 'bin' j
- P_{dt}^k: Total monthly precipitation in period k
- $\{\gamma_r t^3\}$: region-specific cubic polynomials in time

Empirical approach II

$Y_{dt} = \sum_{j=1}^{15} \theta_j T_{dt}^j + \delta^K P_{dt}^{Kharif} + \delta^R P_{dt}^{Rabi} + \alpha_d + \beta_t + \{\gamma_r t^3\} + \varepsilon_{dt}$

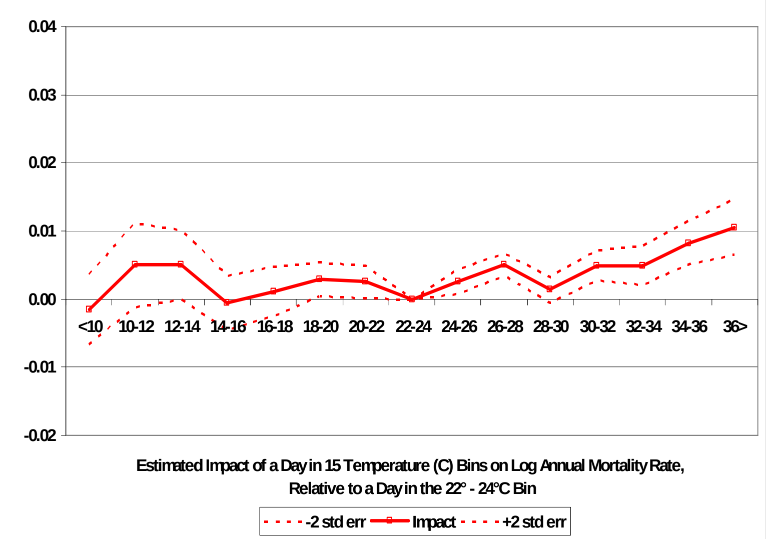
- Intuition:
  - Temperature is not storable, so total annual impact is sum of each day's impact (with unknown lags).
  - Water is somewhat storable. But effects of rain may differ throughout agricultural year.

- Other adjustments:
  - Weight by population
  - Cluster at district level

- Will present temperature results first (15 coefficients best seen graphically), then rainfall.

Temperature and All Ages Death Rate

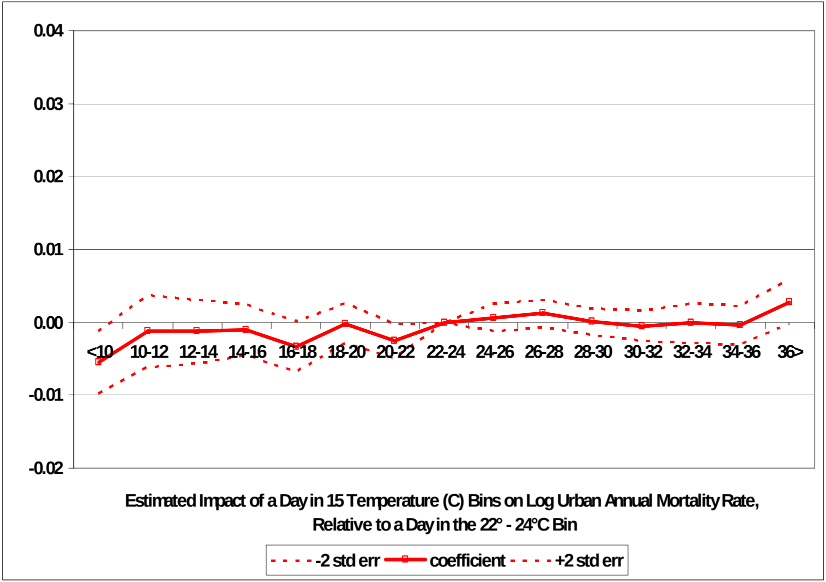
$Y_{dt} = \sum_j \theta_j T_{dt}^j + \delta^K P_{dt}^{Kharif} + \delta^R P_{dt}^{Rabi} + \alpha_d + \beta_t + \{\gamma_r t^3\} + \varepsilon_{dt}$ — 15 $\widehat{\theta}_j$'s plotted



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

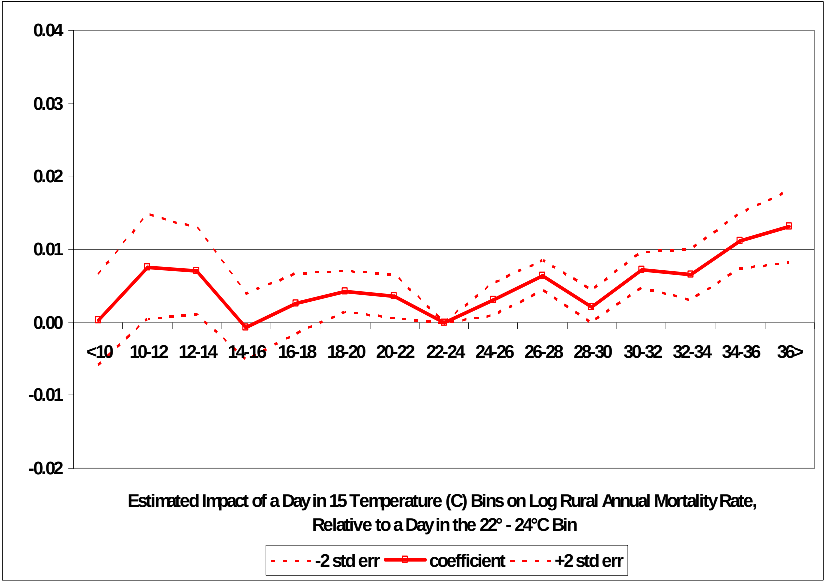
Temperature and All Ages Death Rate

VSI data: Urban India with 95% confidence interval



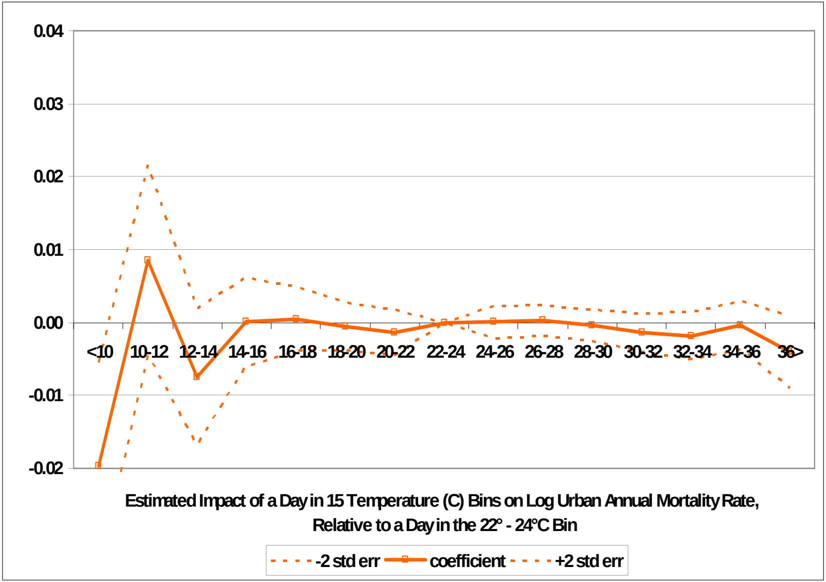
Temperature and All Ages Death Rate

VSI data: Rural India with 95% confidence interval



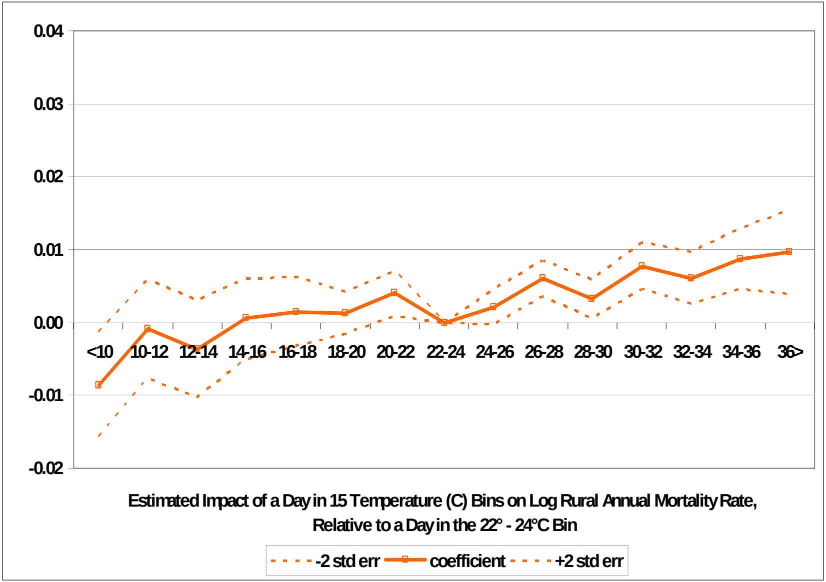
Temperature and Infant Death Rate

VSI data: Urban India with 95% confidence interval



Temperature and Infant Death Rate

VSI data: Rural India with 95% confidence interval

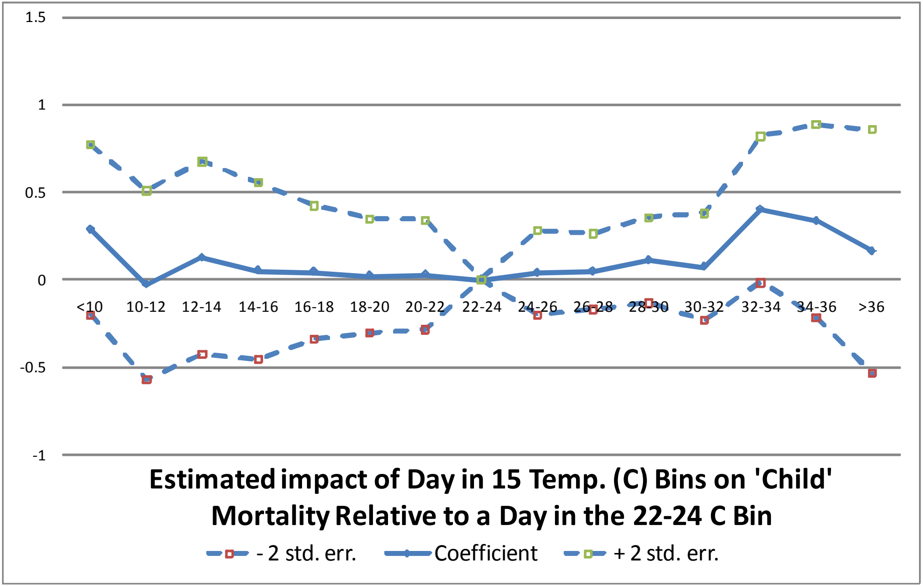


Robustness Check: DHS Data

- Potential concern over quality of registration data
- Check mortality results using independent data source: DHS surveys in 1993 and 1999
- DHS Surveys:
    - Representative survey of all mothers aged 15-49 alive in survey year
    - Mothers asked about all children
    - Mothers recall year of birth of children, and age at death of dead children
    - Use this to construct sample of death events among ‘children’ (aged 0-37)
    - Jain (1985): 47% of deaths occur before the age of 5

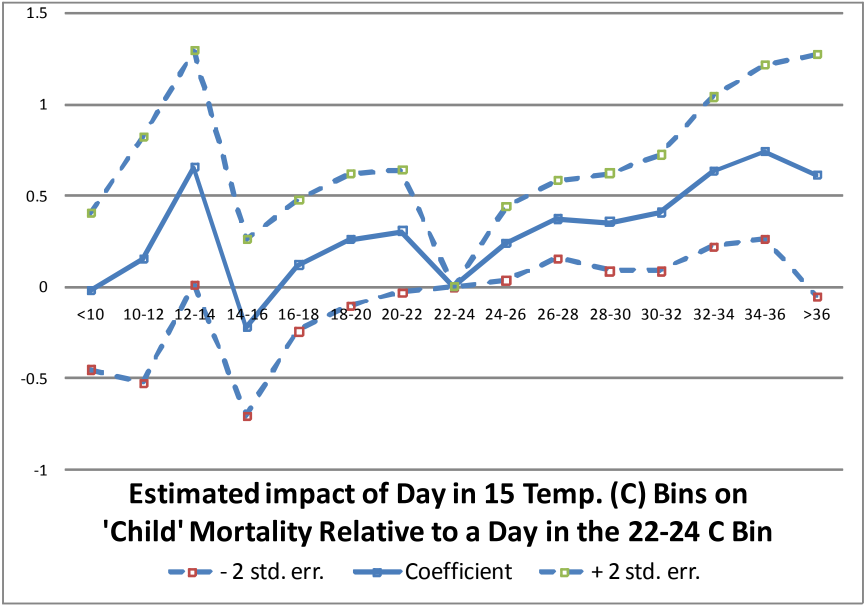
Temperature and ‘Child’ Death Rate

DHS data: Urban India with 95% confidence interval



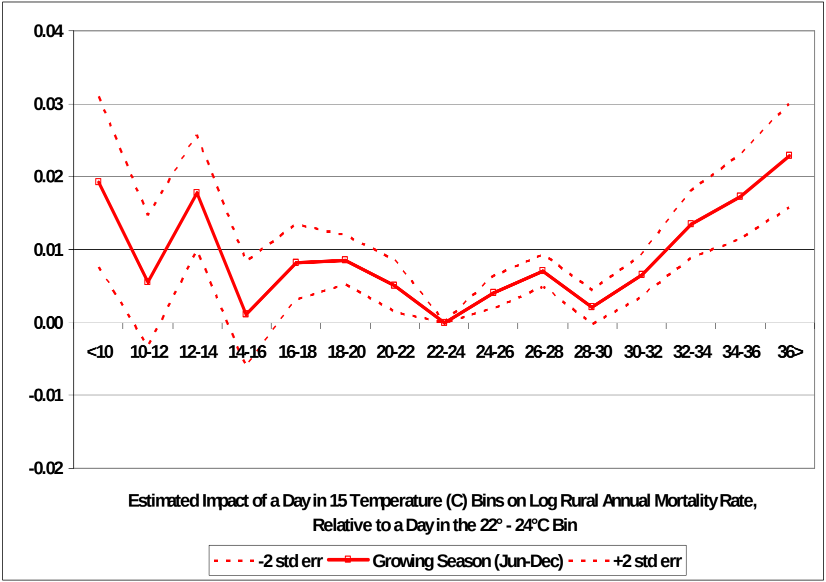
Temperature and ‘Child’ Death Rate

DHS data: Rural India with 95% confidence interval



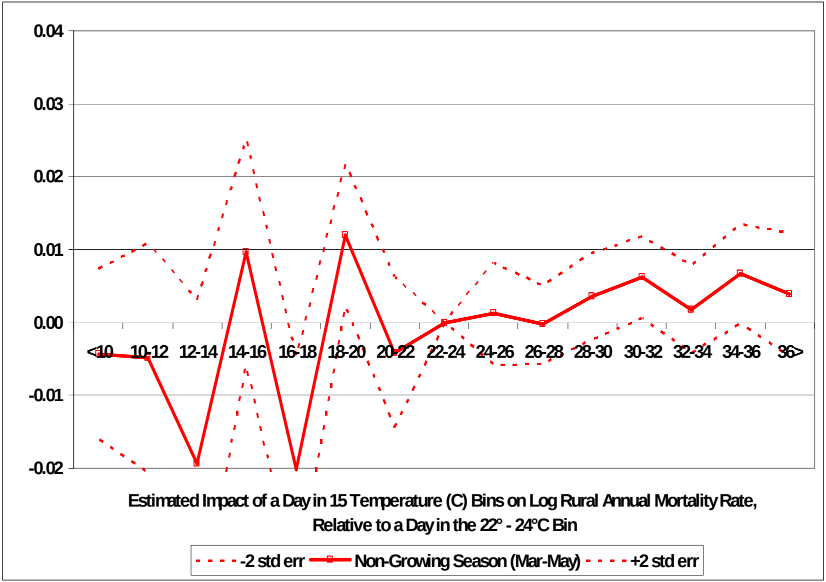
Timing: Growing Season

VSI data: Total deaths in Rural India with 95% confidence interval



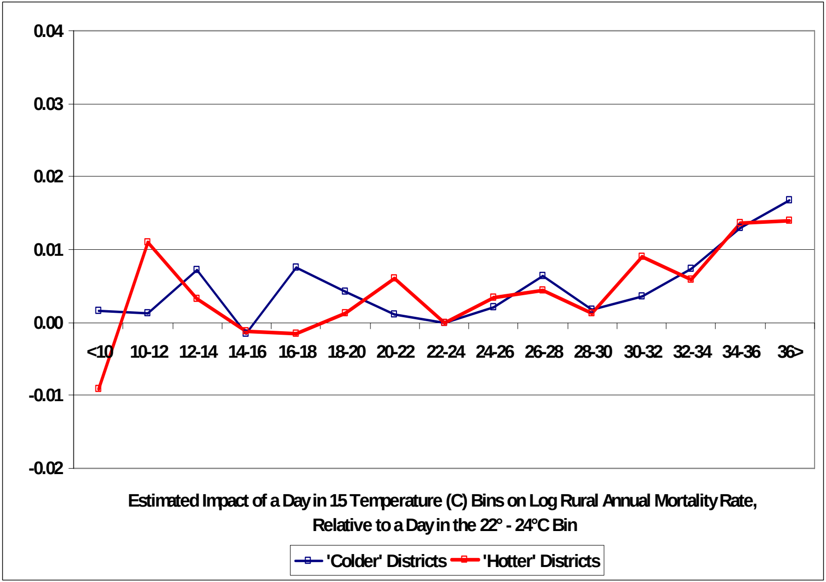
Timing: Non-Growing Season

VSI data: Total deaths in Rural India with 95% confidence interval



Adjustment? Hot vs Cold Areas

VSI data: Total deaths in Rural India



A Parametric Approach

- Use more parametric specification for temperature and rainfall

$$
\begin{aligned}
Y_{dt} &= \theta DD_{dt} + \delta^{\text{kharif}} P_{dt}^{\text{kharif}} + \delta^{\text{rabi}} P_{dt}^{\text{rabi}} \\
&+ \alpha_d + \beta_t + \{\gamma_r t^3\} + \varepsilon_{dt}
\end{aligned}
$$

- DD_{dt} = 'degree-days': Cumulative number of degrees (above 32° C)-times-days in year t
  - Common approach in epidemiology/agronomy
  - Justification: Living organisms (especially humans and food crops) tend to cope well until temperatures exceed 32° C

Parametric Approach: Results

$$Y_{dt} = \theta DD_{dt} + \delta^{\text{kharif}} P_{dt}^{\text{kharif}} + \delta^{\text{rabi}} P_{dt}^{\text{rabi}} + \alpha_d + \beta_t + \{\gamma_r t^3\} + \varepsilon_{dt}$$

	Rural	Urban
Dep. var.: log total mortality rate	(1)	(2)
GROWING SEASON [Jun-Dec]:		
Temp. (degree-days)	0.0265	0.0081
	(0.0047)***	(0.0039)**
Kharif rainfall marg. effect (mm) [Jun-Sep]	0.0127	0.0056
	(0.0044)***	(0.0027)
Rabi rainfall marg. effect (mm) [Oct-Dec]	-0.0355	-0.0003
	(0.0099)***	(0.0105)
NON-GROWING SEASON [Mar-May]:		
Temp. (degree-days)	0.0018	0.0018
	(0.0043)	(0.0031)
Rainfall marg. effect (mm)	-0.0142	0.0294
	(0.0249)	(0.0197)

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

Outline of Talk

Background and Predictionns

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Mechanisms: Weather and Income

- Recap: <u>Large</u> effects of both temperature and rainfall on death rates in rural India but not in urban India (not even infants).
- Begs important questions:
  1. Why are there large effects of weather on death in rural India, and why not in urban India?
  2. Why are these effects absent during the non-growing season (the <u>hot</u> season), even in rural India?

Indirect Effect: Implications

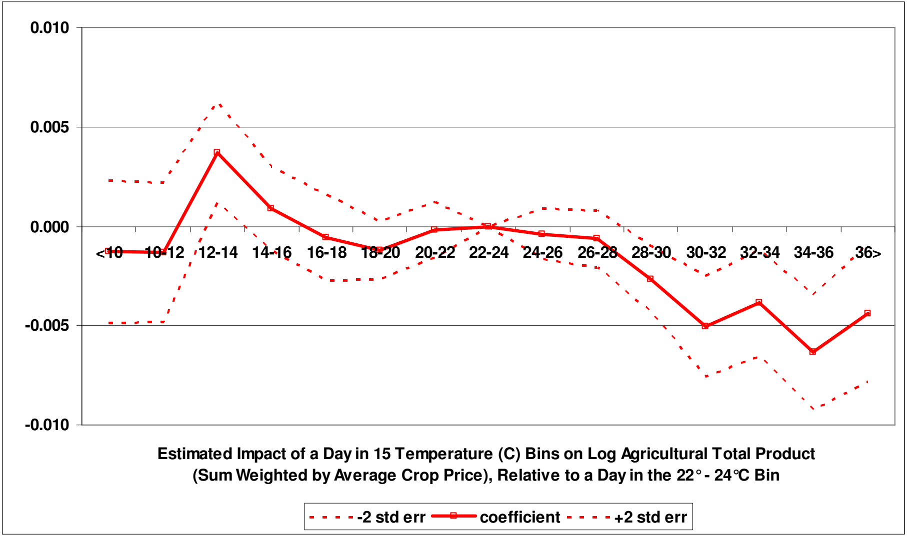
- Bad GS weather (but not NGS weather) causes:
  - Lower agricultural yields
  - Higher agricultural prices
  - Lower Rural wages (but not Urban wages)
  - Lower Rural bank deposits (but not Urban bank deposits)

  - Higher adult and infant Rural mortality rate (but not adult or infant Urban mortality rate)

- Agricultural results extend work of Guiteras (2008) and Sanghi et al (1998)

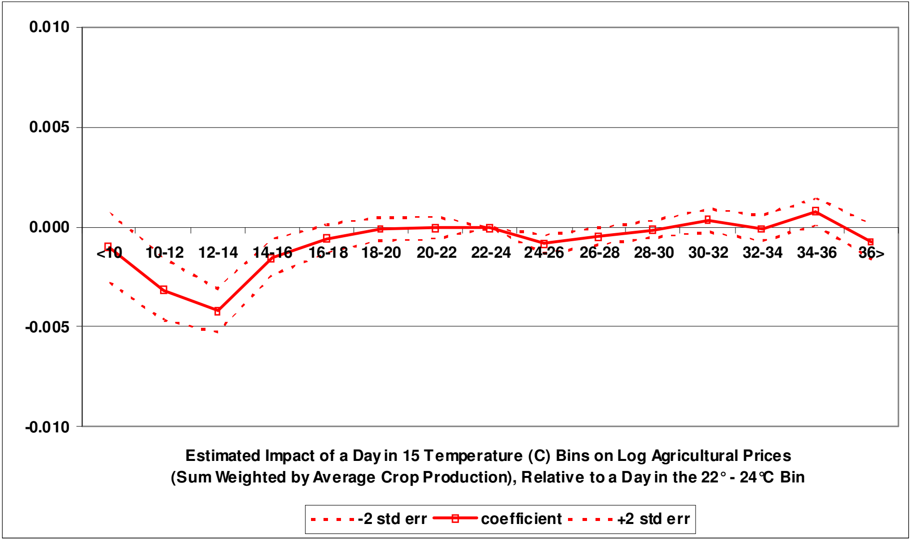
Temperature and Agricultural Yields

Yield: Real aggregate agricultural output per acre



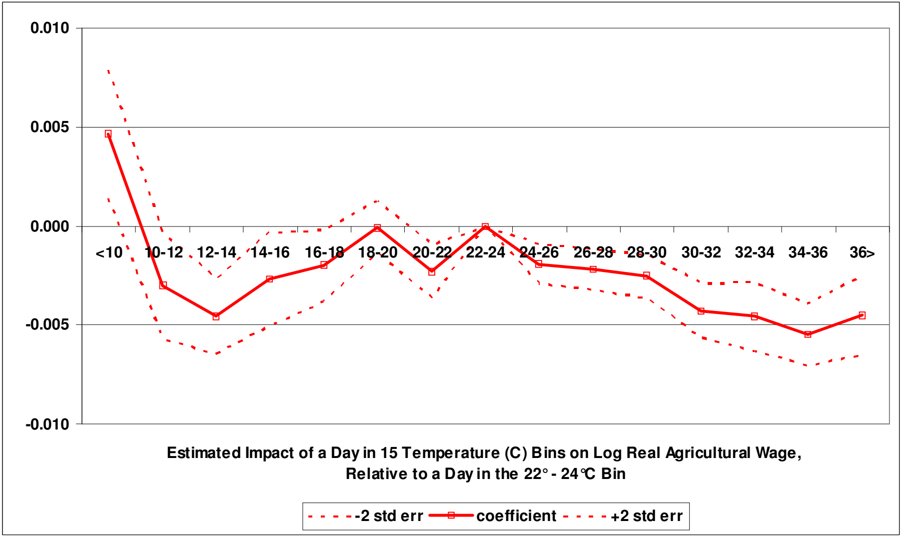
Temperature and Agricultural Prices

Agricultural price index



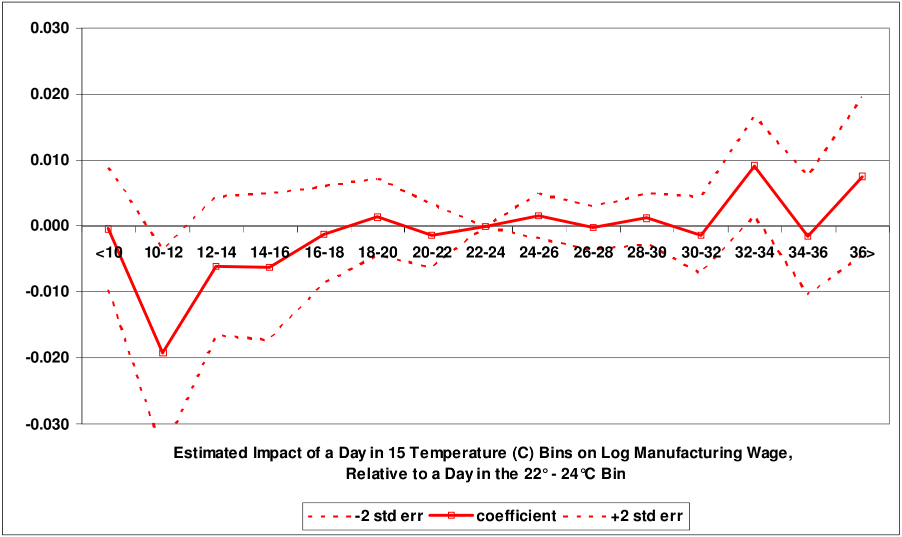
Temperature and Agricultural Wages

Real agricultural laborers' wages



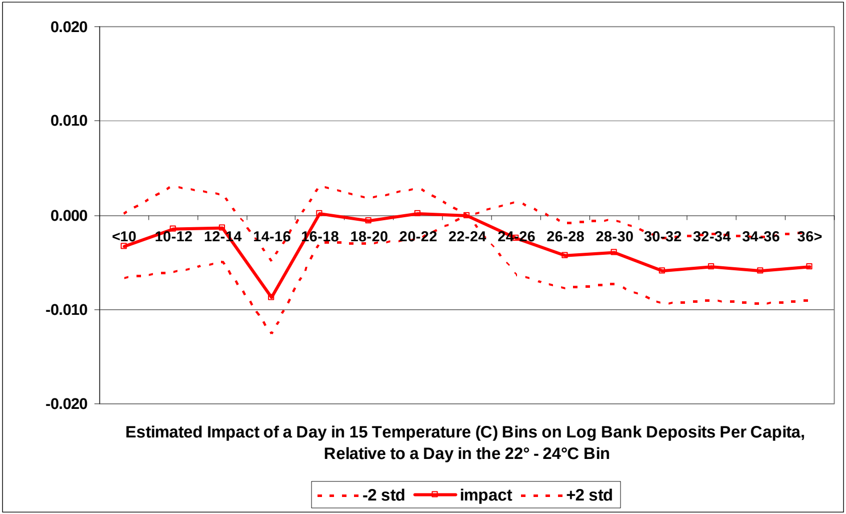
Temperature and Urban Wages

Urban wage: state-level real manufacturing earnings per worker



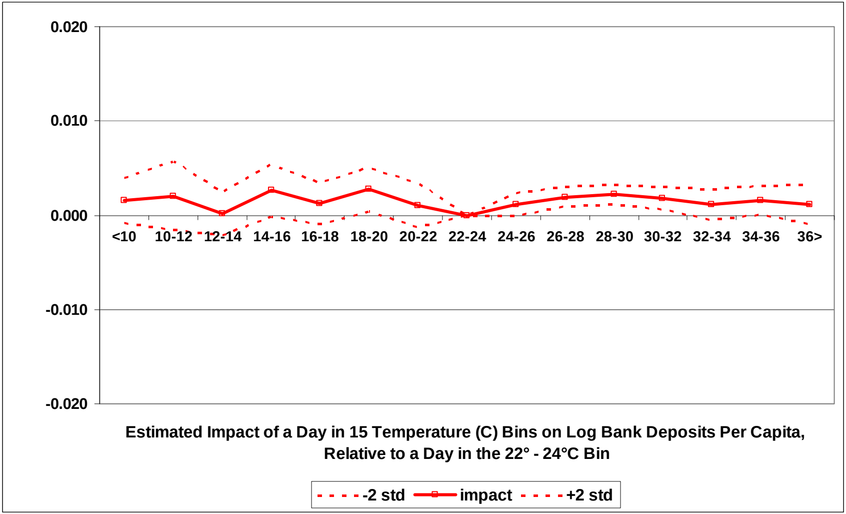
Temperature and Bank Deposits:

Bank deposits per capita in <u>Rural</u> areas



Temperature and Bank Deposits:

Bank deposits per capita in Urban areas



Parametric Approach: Results

$$Y_{dt} = \theta DD_{dt} + \delta^{\text{kharif}} P_{dt}^{\text{kharif}} + \delta^{\text{rabi}} P_{dt}^{\text{rabi}} + \alpha_d + \beta_t + \{\gamma_r t^3\} + \varepsilon_{dt}$$

Dependent variable: log...	Yields	Prices	Ag. W	Man. W
	(1)	(2)	(3)	(4)
GROWING SEASON [Jun-Dec]:				
Temp. (degree-days)	-0.0090	0.0022	-0.0037	-0.0014
	(0.0033)***	(0.0007)***	(0.0015)***	(0.0104)
Kharif rainfall marg. effect (mm)	0.0268	-0.0031	0.0047	0.0005
	(0.0040)***	(0.0007)***	(0.0018)***	(0.0103)
Rabi rainfall marg. effect (mm)	0.0520	-0.0088	0.0078	-0.0656
	(0.0071)***	(0.0022)***	(0.0053)	(0.0506)
NON-GROWING SEASON [Mar-May]:				
Temp. (degree-days)	0.0040	0.0011	0.0013	0.0140
	(0.0022)*	(0.0007)	(0.0014)	(0.0077)
Rainfall marg. effect (mm)	0.0062	0.0055	-0.0163	-0.0123
	(0.0102)	(0.0037)	(0.0081)**	(0.0582)

Notes: Regressions in columns (1)-(3) include district fixed effects, year fixed effects and region-specific cubic time trends; in column (4), state fixed effects, year fixed effecs and region-specific cubic time trends. Regressions weighted by population. Standard errors clustered by district in cols (1)-(3) and state in col (4).

An Interpretation I

- Consider a simple 'model' of agricultural income and death:

$$
\begin{aligned}
\ln\left(\frac{Y}{L}\right)_{dt} &= a_p^K P_{dt}^K + a_p^R P_{dt}^R + a_T T_{dt} + \varepsilon_{dt} \\
\ln M_{dt} = \beta \;\; \ln & \left(\frac{Y}{L}\right)_{dt} + d_p^K P_{dt}^K + d_p^R P_{dt}^R + d_T T_{dt} + \varepsilon'_{dt}
\end{aligned}
$$

- Under exclusion restriction $d_p^R = 0$, this system is just identified
- β is the agricultural income-death elasticity

An Interpretation II

- Estimates based on this exclusion restriction imply:
  - $\widehat{\beta} = -0.68$
  - Indirect 'income channel' accounts for 23 % of reduced-form temperature-death effect.
  - Kharif rainfall-death effect: 'income channel' is $\widehat{\beta}\widehat{a_p^K}$ = -0.01822, while 'direct' (eg disease) channel is $\widehat{d_p^K} = 0.0127$. They are roughly offsetting.

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Implications for Policy

- We have documented a large reduced-form impact of both temperature and rainfall extremes on mortality in India from 1956-2000

- What does this imply for policy? We look at two examples with back-of-the-envelope calculations:
    1. What is the cost per life saved of an income support policy (ie 'social weather insurance') designed to hold death rate constant?
    2. Looking into the future: As India's climate changes throughout the 21st Century, what are the implications for mortality?

Income Support Policy

- Weather (especially temperature) is observable and verifiable
- A very simple government program could index cash transfers on the basis of daily temperature and rainfall realizations
- Estimated income-death elasticity of $\widehat{\beta}=$-0.68 implies approximately \$75 per life saved (adult or child)

Implications of Climate Change I

- Models of C.C. predict ΔT_d and ΔP_d
- We use our earlier estimates of the mortality consequences of weather variation to estimate the mortality consequences of <u>predicted</u> ΔT_d and ΔP_d:

$$\widehat{\Delta Y_d} = \sum_j \widehat{\theta_j} \Delta T_d^j + \sum_{m=1}^{12} \widehat{\delta_m} \Delta P_d^m$$

- Likely to be an <u>overestimate</u> (short-run vs. long-run adaptation)

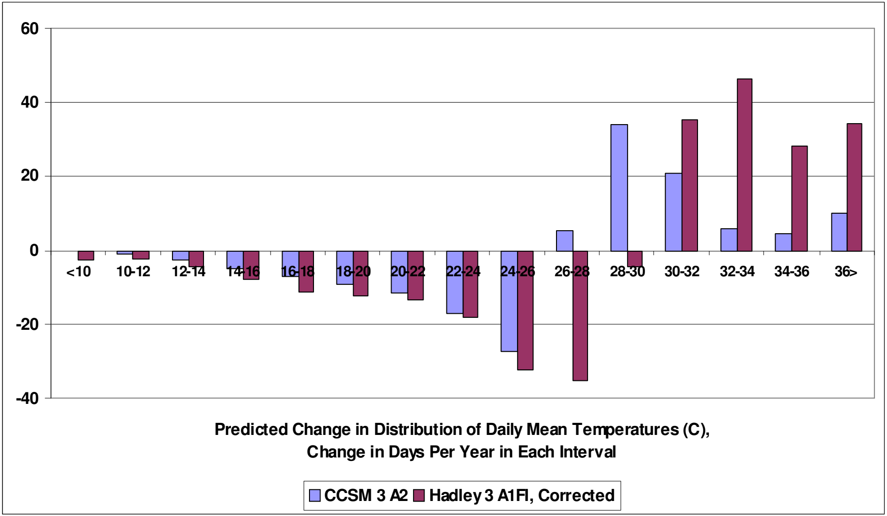
Implications of Climate Change II

- 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
  - 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 pop-weighted average

Predicted Change in Temp. Distribution



Predicted Impact of CC on Mortality

Percentage impacts: $\widehat{\Delta Y_d} = \sum_j \widehat{\theta}_j \Delta T_d^j + \sum_{m=1}^{12} \widehat{\delta_m} \Delta P_d^m$, by 2070-2099

	Impact of Change in Days with Temperature:			Total Temperature Impact	'Early' Precipitation Impact	'Late' Precipitation Impact	Temperature and Precipitation Impact
	<16C	**16C-32C**	**>32C**				
	(1a)	(1b)	(1c)	(2)	(3a)	(3b)	(4)
A. Based on Hadley 3, A1FI							
Pooled	-0.019	-0.113	0.732	0.599	0.019	-0.010	0.608
	(0.031)	(0.047)	(0.119)	(0.117)	(0.006)	(0.003)	(0.118)
Rural Areas	-0.038	-0.140	0.913	0.735	0.023	-0.015	0.744
	(0.040)	(0.057)	(0.149)	(0.149)	(0.007)	(0.004)	(0.151)
Urban Areas	0.045	0.014	0.159	0.218	0.003	0.002	0.223
	(0.033)	(0.057)	(0.114)	(0.102)	(0.004)	(0.004)	(0.103)
B. Based on CCSM3, A2							
Pooled	-0.010	0.061	0.164	0.214	0.009	-0.019	0.204
	(0.013)	(0.040)	(0.009)	(0.057)	(0.007)	(0.005)	(0.058)
Rural Areas	-0.017	0.076	0.206	0.248	0.012	-0.028	0.264
	(0.016)	(0.049)	(0.035)	(0.072)	(0.008)	(0.007)	(0.071)
Urban Areas	0.011	0.037	0.043	0.092	-0.006	0.003	0.089
	(0.013)	(0.039)	(0.024)	(0.049)	(0.005)	(0.007)	(0.050)

Predicted Impact of CC on Mortality

Percentage impacts: $\widehat{\Delta Y_d} = \sum_j \widehat{\theta}_j \Delta T_d^j + \sum_{m=1}^{12} \widehat{\delta_m} \Delta P_d^m$, rural only

	Impact of Change in Days with Temperature:			Total Temperature Impact	'Early' Precipitation Impact	'Late' Precipitation Impact	Temperature and Precipitation Impact
	<16C	16C-32C	>32C				
	(1a)	(1b)	(1c)	(2)	(3a)	(3b)	(4)
A. Based on Hadley 3, A1FI							
2010-2039	-0.014	0.052	0.061	0.099	-0.006	-0.006	0.086
	(0.015)	(0.025)	(0.011)	(0.036)	(0.002)	(0.002)	(0.036)
2040-2069	-0.019	0.007	0.302	0.290	0.015	-0.006	0.299
	(0.026)	(0.026)	(0.047)	(0.064)	(0.005)	(0.002)	(0.065)
2070-2099	-0.019	-0.113	0.732	0.599	0.019	-0.010	0.608
	(0.031)	(0.047)	(0.119)	(0.117)	(0.006)	(0.003)	(0.118)
B. Based on CCSM3, A2							
2010-2039	-0.002	0.066	-0.079	-0.015	-0.001	-0.012	-0.028
	(0.010)	(0.017)	(0.014)	(0.019)	(0.006)	(0.003)	(0.020)
2040-2069	-0.007	0.094	0.004	0.091	0.002	-0.017	0.076
	(0.006)	(0.022)	(0.005)	(0.022)	(0.006)	(0.005)	(0.023)
2070-2099	-0.010	0.061	0.164	0.214	0.009	-0.019	0.204
	(0.013)	(0.040)	(0.009)	(0.057)	(0.007)	(0.005)	(0.058)

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Summary

- Both temperature and rainfall extremes play a large role in the health lives of India's rural poor:
  - One SD more degree-days (over 32 C) leads to 68 % higher death rate
  - Temperature: 10 $\times$ 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-indexed income support policy would cost only $75 per life saved (adult or child)
  - Standard global warming scenarios imply dire upper-bound (limited adaptation) consequences