Weather and Death in India: Mechanisms and Implications of Climate Change

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Context:

- Large literature for US and Europe on impact of exposure to extreme temperatures (heat) and 'health' (event-study analysis)

- Physiological mechanisms and at-risk populations identified

- Motivated by analysis of public health interventions, and now by concerns about climate change

- $\Rightarrow$ Much smaller literature for developing countries, key focus on <u>rainfall</u>, from perspective of consumption smoothing studies, insurance, etc

Context and motivation:

- $\Rightarrow$ Weather shocks and death are likely to be much more connected in developing countries for several reasons:
- *Less income and technology to 'adapt': (e.g. AC, irrigation)*
- *Greater importance of weather-dependent economic activities (e.g. agriculture)*

- $\Rightarrow$ Weather shocks get propagated to rest of economy, <u>and</u> may reduce possibilities for 'smoothing'
- $\Rightarrow$ Both phenomena may contribute to excess mortality

- $\Rightarrow$ No proper micro founded studies to ascertain this

- $\Rightarrow$ Important since impact of climate change likely of much larger magnitude in developing countries

Setting: India

- GDP per capita: $640

- Life expectancy: about 65, median age 25,
- Crude death rate: 8 per 1,000

- Agriculture accounts for 22% of GDP and 60% of employment

- **Rural / urban sectors:**
- 75% of population lives in rural sectors (<5,000)
- Higher poverty rates (39.4 vs. 22.5, 1983)
- Higher dependence of agriculture (income and food)

- $\Rightarrow$ Rural population’s real income more exposed to weather shocks than urban population

Question #1

- **What is the impact of inter-annual variation in weather on health in India with district-level data from 1957-2000?**

- *Impact of exposure to extreme temperatures (heat)*
- *Impact of monthly rainfall*

- $\Rightarrow$ *Mortality rate (infants, ages 1+)*
- $\Rightarrow$ *Registration data*

- $\Rightarrow$ *Rural areas vs. urban areas*

Question #2

- **What are the mechanisms through which exposure to extreme temperatures impact human health in developing countries?**

- **What explains rural / urban differences?**

- *Agricultural wages (rural) and manufacturing wages (urban)*
- *Agricultural product and prices*
- *Labor supply adjustments*
- *Deposits and credits disbursements from banks*

Question #3

- **Are there interventions/infrastructure/policies that help mitigate the impact of extreme temperatures?**

- *Interaction of temperature effects with:*

- *Local public health infrastructure*
- *Fraction of land under irrigation*
- *Level of per-capita expenditure in district*
- *Availability of railroads (migration)*

Question #4

- **What are the implications of all this for the health costs of climate change in developing countries?**

- Developing countries are likely to suffer the most, few comprehensive studies of health impacts

- Inter-annual variation provides information on the costs of climate change:
  - **<u>Overestimate</u>** of damages because individuals can engage in a limited set of adaptations in response to inter-annual variation

- Can we identify simple interventions that would mitigate health impacts of climate change in India?

Data sources:

- 1. Vital statistics
- 2. Historical weather
- 3. Agricultural labor market and output
- 4. Manufacturing wage (urban wage)
- 5. Bank credits and deposits
- 6. Climate change projections
- $\Rightarrow$ All district-level data, with rural/urban entries when relevant (except manufacturing wage)

Empirical approach

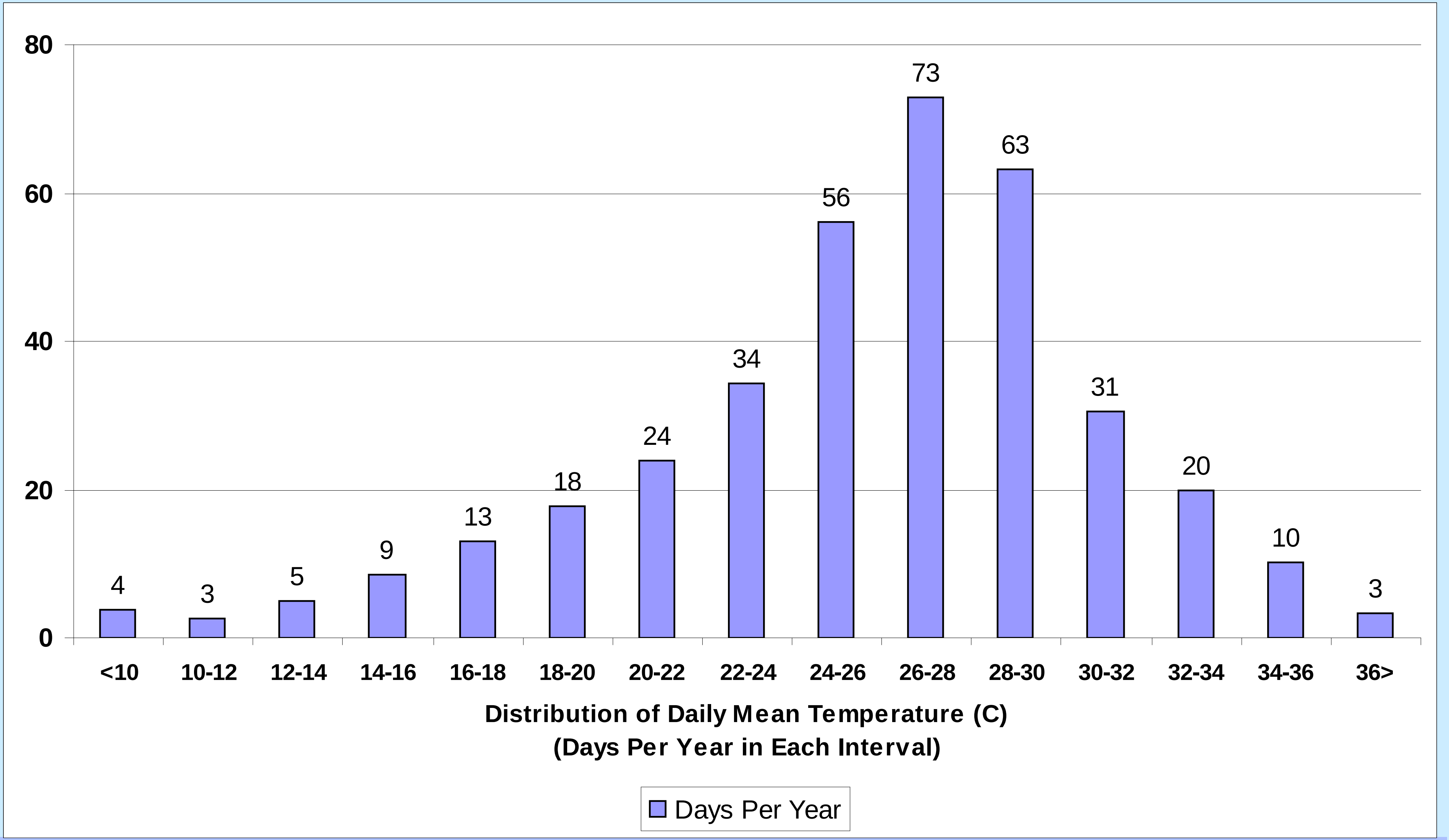
- 1. Estimate district-by-age group models for outcomes (log mortality rates, wages, labor supply, etc)

- (i) Include 15 separate variables for temperature to allow for nonlinearities; 12 variables for monthly precipitation
- $\Rightarrow$ *Also models with average daily temperature (single-index of exposure)*

- (ii) Include district-by-area fixed effects, year-by-area fixed effects, and region-specific time trends

- $\Rightarrow$ Exploit the substantial and presumably random year-to-year variation in temperature and precipitation distributions

Distribution of daily mean temperatures, India 1957-2000



Summary of Results:

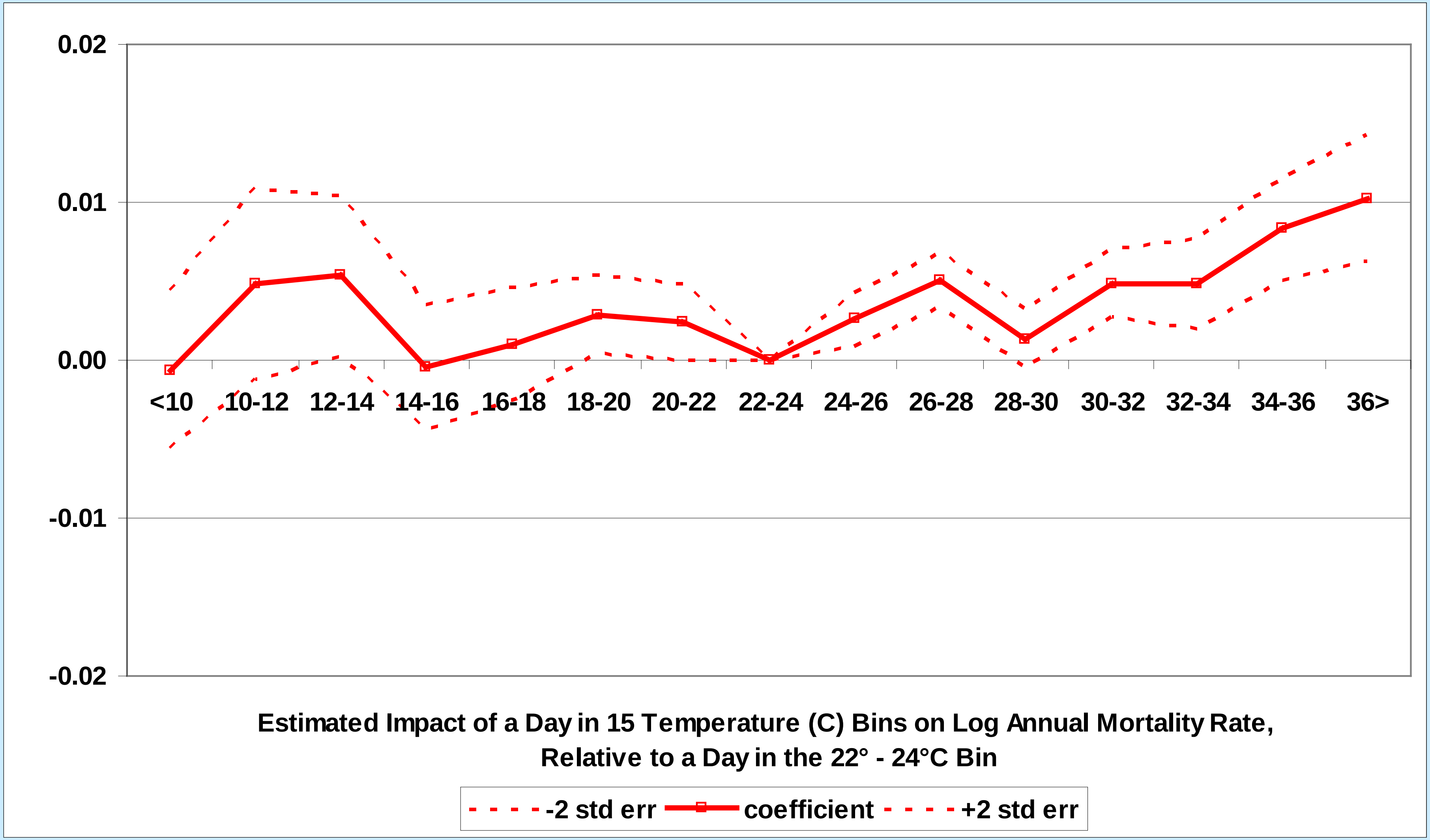
- **1. Relationship between daily temperature exposure and mortality is nonlinear and the magnitude of excess mortality associated with extremes is large**

- <u>One</u> additional day with a mean temperature above 32°C increases the annual mortality rate by roughly 0.8% (relative to a day with temperature in the 22°-24°C range)

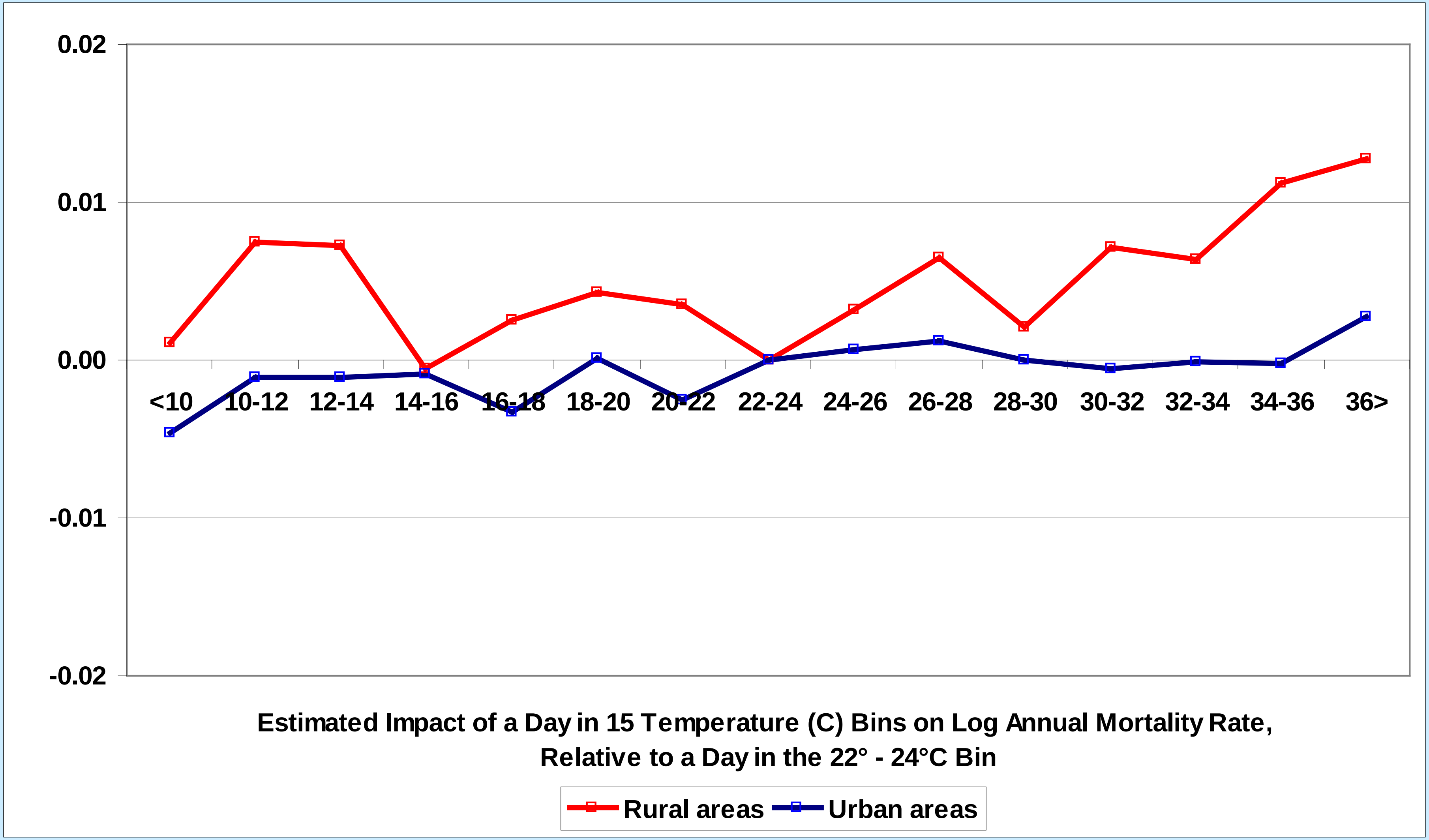
- Alternatively, a 1°C increase in average daily temperatures leads to a 10% increase in annual mortality rates

- ***Most of this effect is concentrated in rural areas***

Estimated Response Function Between Temperature Exposure and Log Annual Mortality Rate (All Ages)



Estimated Response Function Between Temperature Exposure and Log Annual Mortality Rate (All Ages, By Rural/Urban Designation)



- **2. Exposure to extreme temperatures in <u>rural</u> areas leads to decline in real income, lower food supply, and lesser availability of smoothing mechanisms**

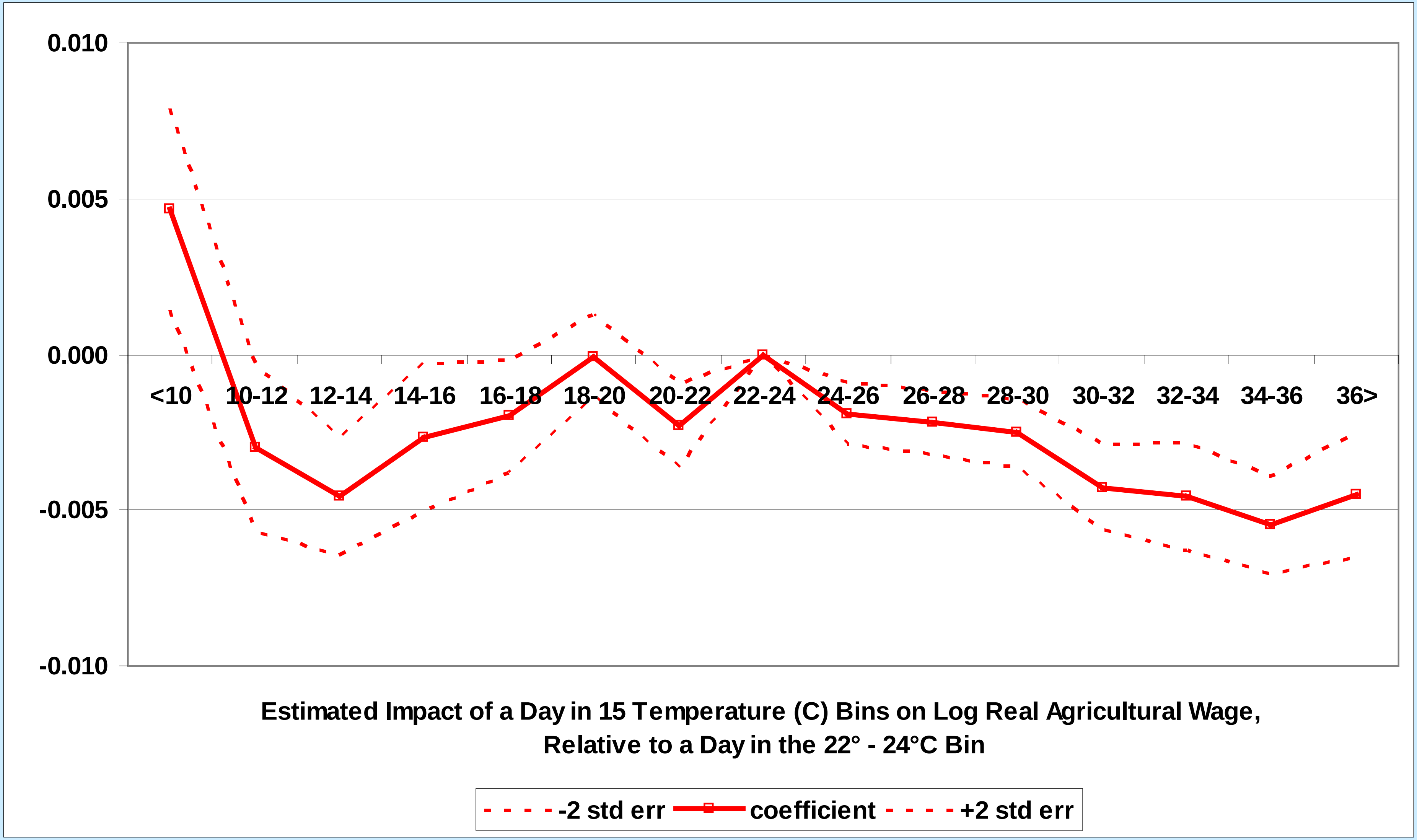
- *Reductions in wage rate of agricultural workers*
  (1°C increase in ADT $\Rightarrow$ 8.5% decline in wage)

- *Little change in labor supply, so incomes down sharply*

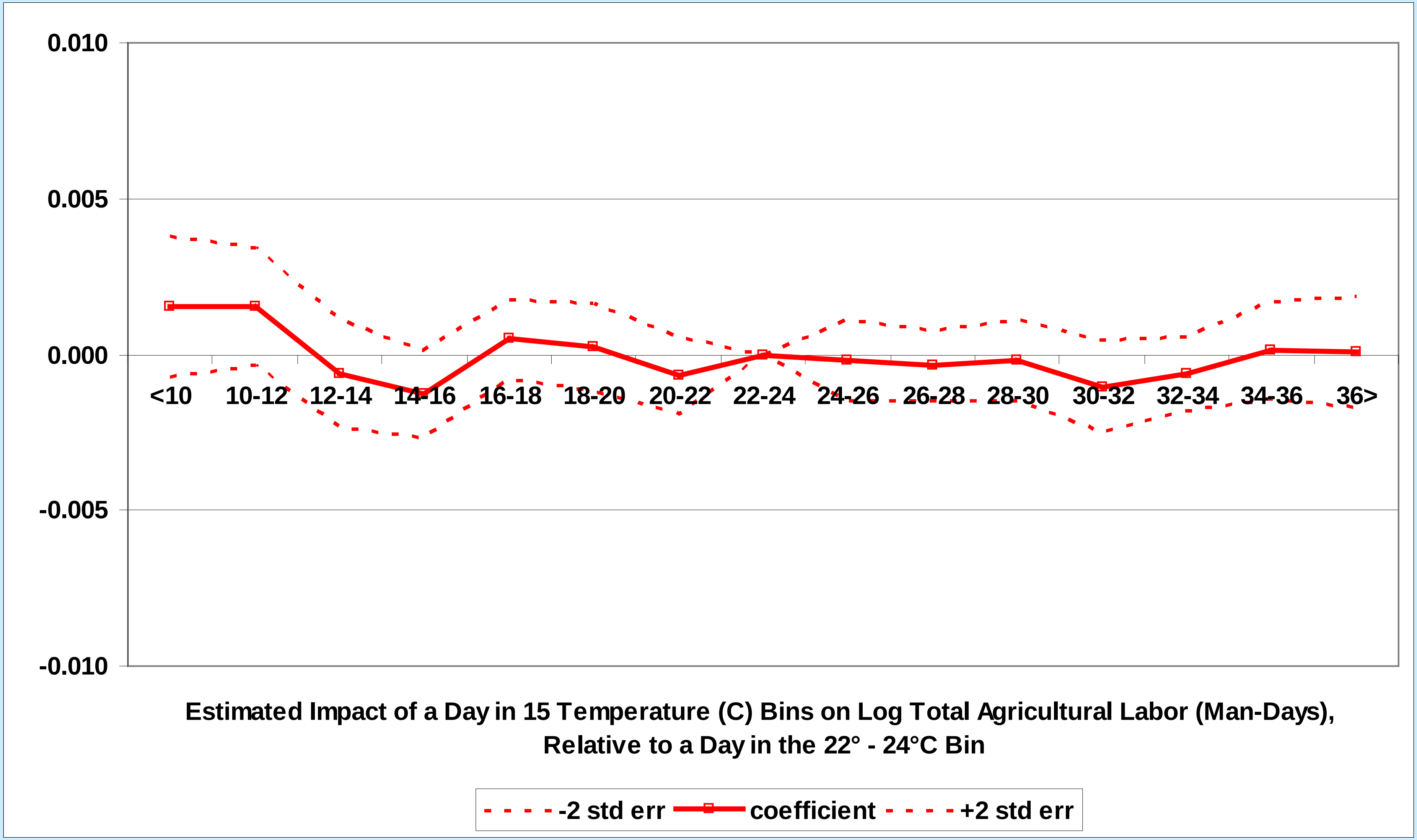
- *Agricultural output declines and prices increase*
  (1°C increase in ADT $\Rightarrow$ 5.4% decline in crop yield, 3.1% increase in crop prices)

- *Decline in bank credits disbursement per capita*
  (1°C increase in ADT $\Rightarrow$ 4.2% decline in credit)

Estimated Response Function Between Temperature Exposure and Log Real Agricultural Wage Rate



Estimated Response Function Between Temperature Exposure and Log Total Agricultural Labor



- **3. Extreme temperatures in <u>urban</u> areas have little real impact**

- *No change in manufacturing wages (if anything, it increases)*

- *No change in bank credits disbursement per capita (if anything, it increases)*

- **4. Some evidence on role of health infrastructure in mitigating temperature shocks**

- *Temperature effects smaller in rural areas with ‘high’ access to hospitals and dispensaries, but difference imprecisely estimated*

- *Very preliminary and incomplete analysis*

- **5. Implications of climate change**

- This inter-annual variation provides information on the costs of climate change:
  - Overestimate of damages because individuals can engage in a limited set of adaptations in response to inter-annual variation

- With this important caveat in mind, the results indicate that end of century climate change will lead to:

- 8%-56% increases in the annual mortality rate

- 16%-71% in rural areas

Outline:

- 1. Conceptual framework
- 2. Data sources and summary statistics
- 3. Econometric methodology
- 4. Results
- 5. Future work and conclusions

Conceptual framework:

- Model that highlights the <u>interplay</u> and the <u>adjustment</u> to the ***direct*** and various ***indirect*** impact channels of weather shocks on health

- Interplay summarized by health production function (weather shock enter directly and through effect on inputs)

- Adjustment to shocks based on ‘life cycle hypothesis’ model, which predicts that households equalize marginal utility of consumption across periods

- $\rightarrow$ Key assumption of this model is the absence of borrowing constraints

Impact margins of weather shocks

- **Direct health effect (heat stress)**
- *Plus disease vectors*

- **‘Real’ impacts**
- Wages, prices

- **Impacts on smoothing mechanisms:**
- Labor supply adjustment
- Formal credit sector (i.e. borrowing from banks)
- *Spending down liquid assets*
- *Informal credit sector*
- *Migration*
- *Change in living arrangements*
- *Etc*

Data sources:

- 1. Vital statistics
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- $\Rightarrow$ All district-level data, with rural/urban entries when relevant (except manufacturing wage)

Vital statistics data

- Source: Vital Statistics of India, 1957-2001
  (registration data collected by village/ward officers)

- **Variables:**
- Universe of ***registered*** deaths
- Mortality (rate per 1,000 population)
- Infant mortality (rate per 1,000 live births)

- Unit of observation is district by rural/urban area

- VSI is only consistent source of district-level vital statistics

- Will investigate reliability with state-level SRS data

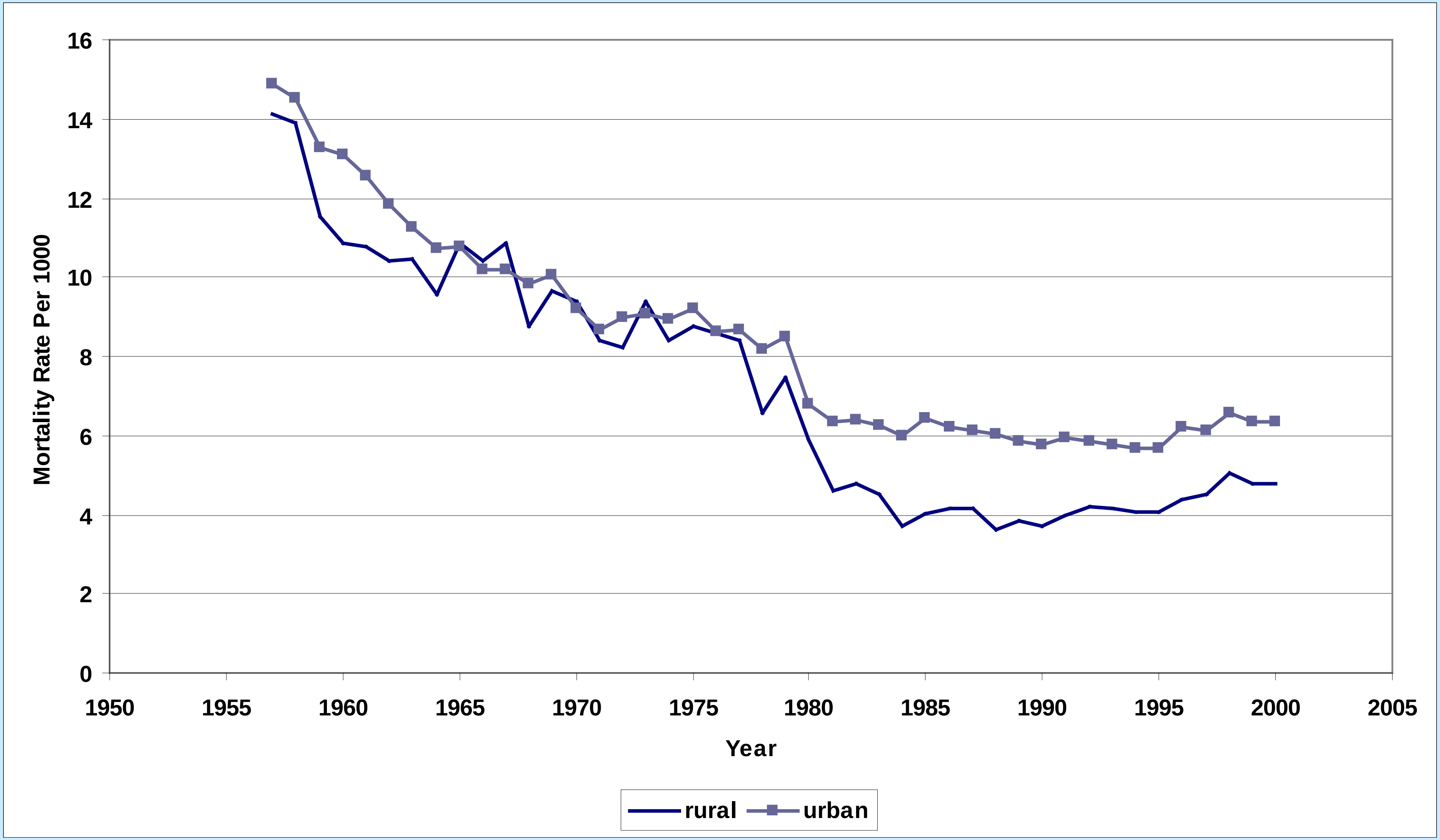
Vital statistics data

- Under-registration a ***major*** issue in India
- Plus missing data: 13% of district*area*year vital statistics missing, especially important in Northeastern states
- Main estimation sample excludes: Assam, Arunachal Pradesh, Haryana, Manipur, Meghalaya, Mizoram, Nagaland, Sikkim, Tripura
- About 85% of total population covered
- Results largely unaffected by inclusion of other states

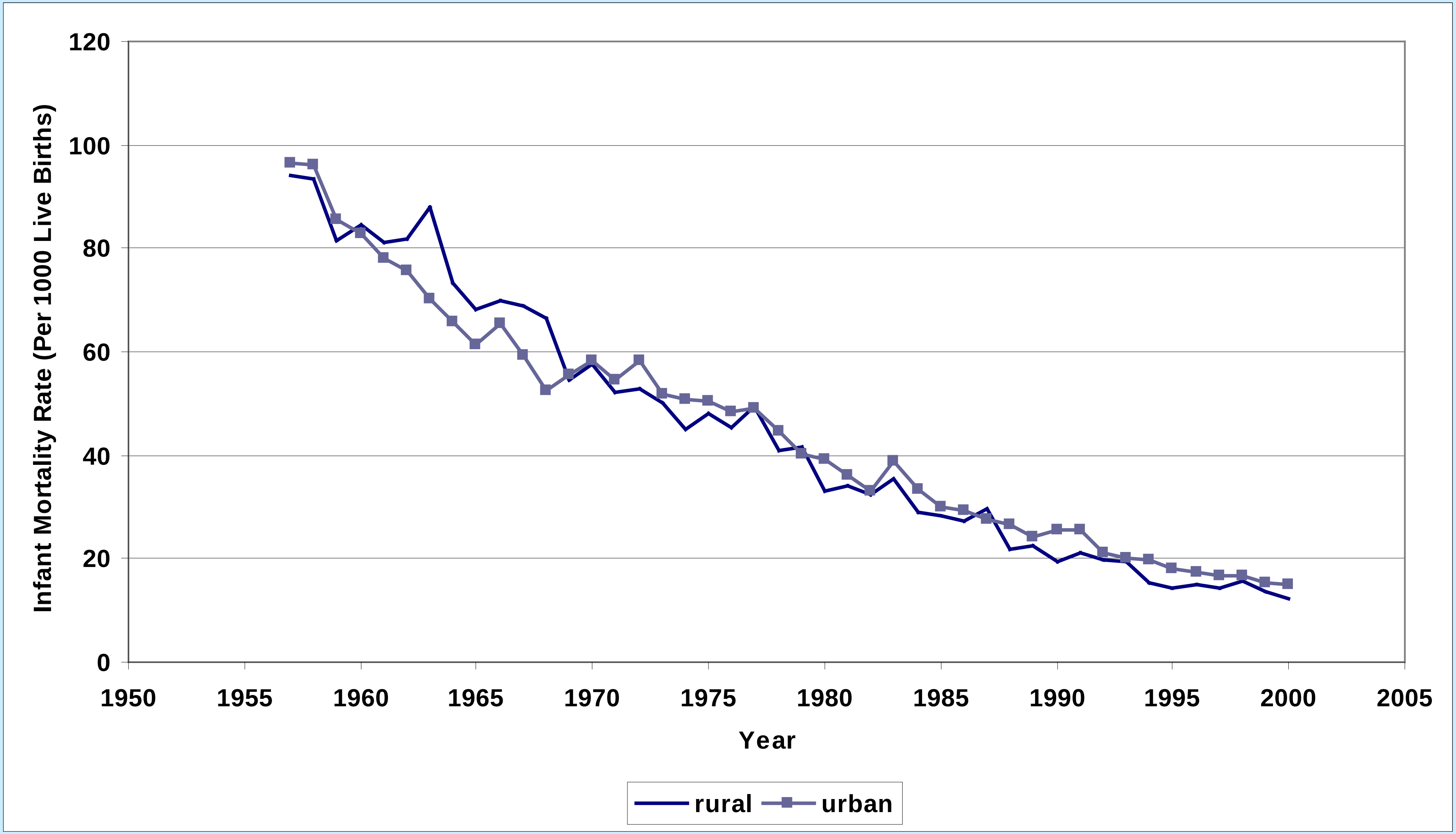
Indian districts

- Administrative division of states
- 342 districts based on 1961 classifications (more now)
- 304 in our main estimation sample
- Most have a rural and urban section
- Among the largest are: 24-Parganas, West Bengal (6.7 Mil., rural and 3.6 Mil, urban) and Greater-Bombay, Maharashtra (7.7 Mil., urban only)
- The smallest is: Lahaul Spiti, Punjab (28,000, rural only)

Trends in annual mortality rate (age 1+)



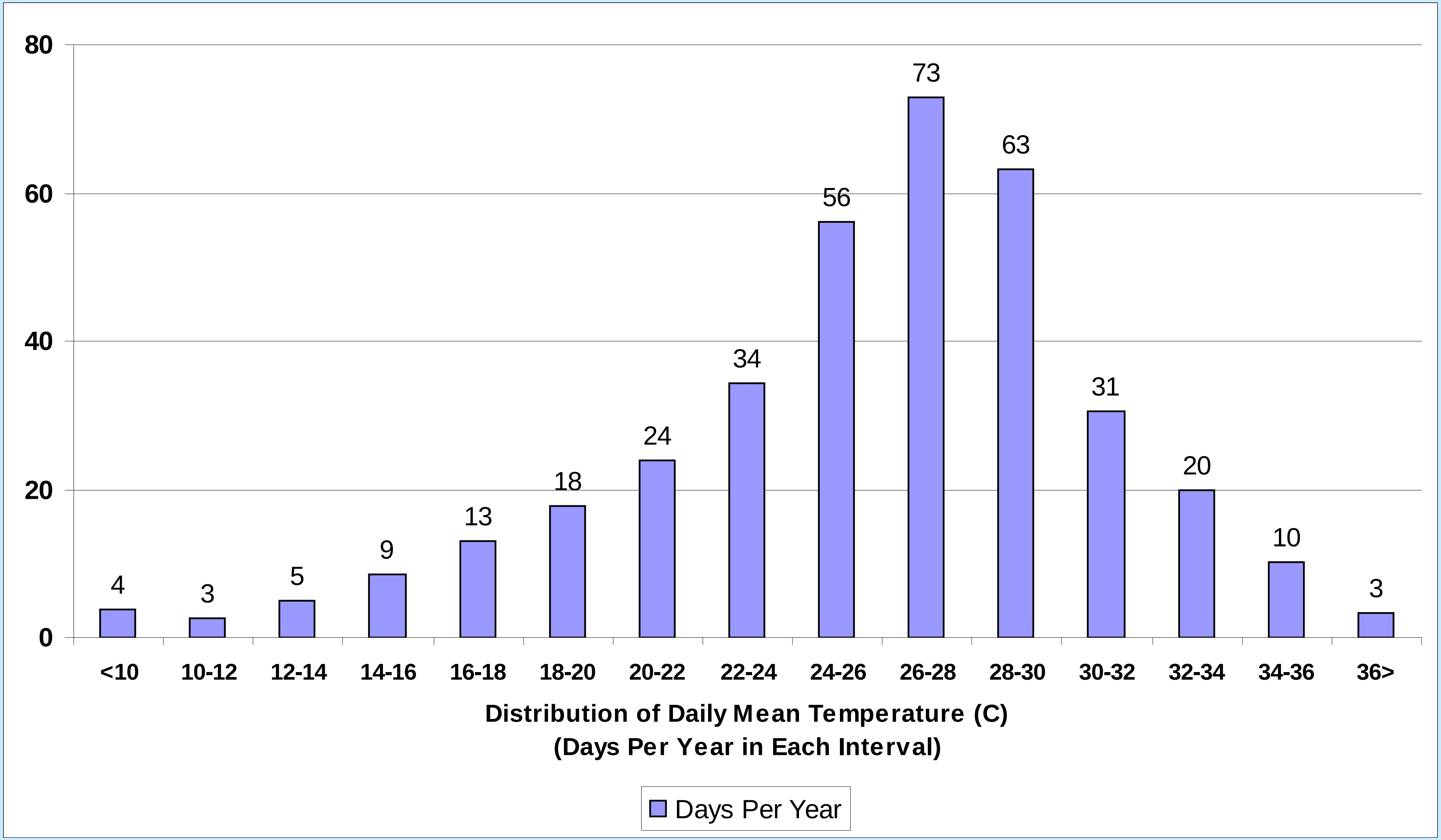
Trends in annual infant mortality rate (age 0-1)



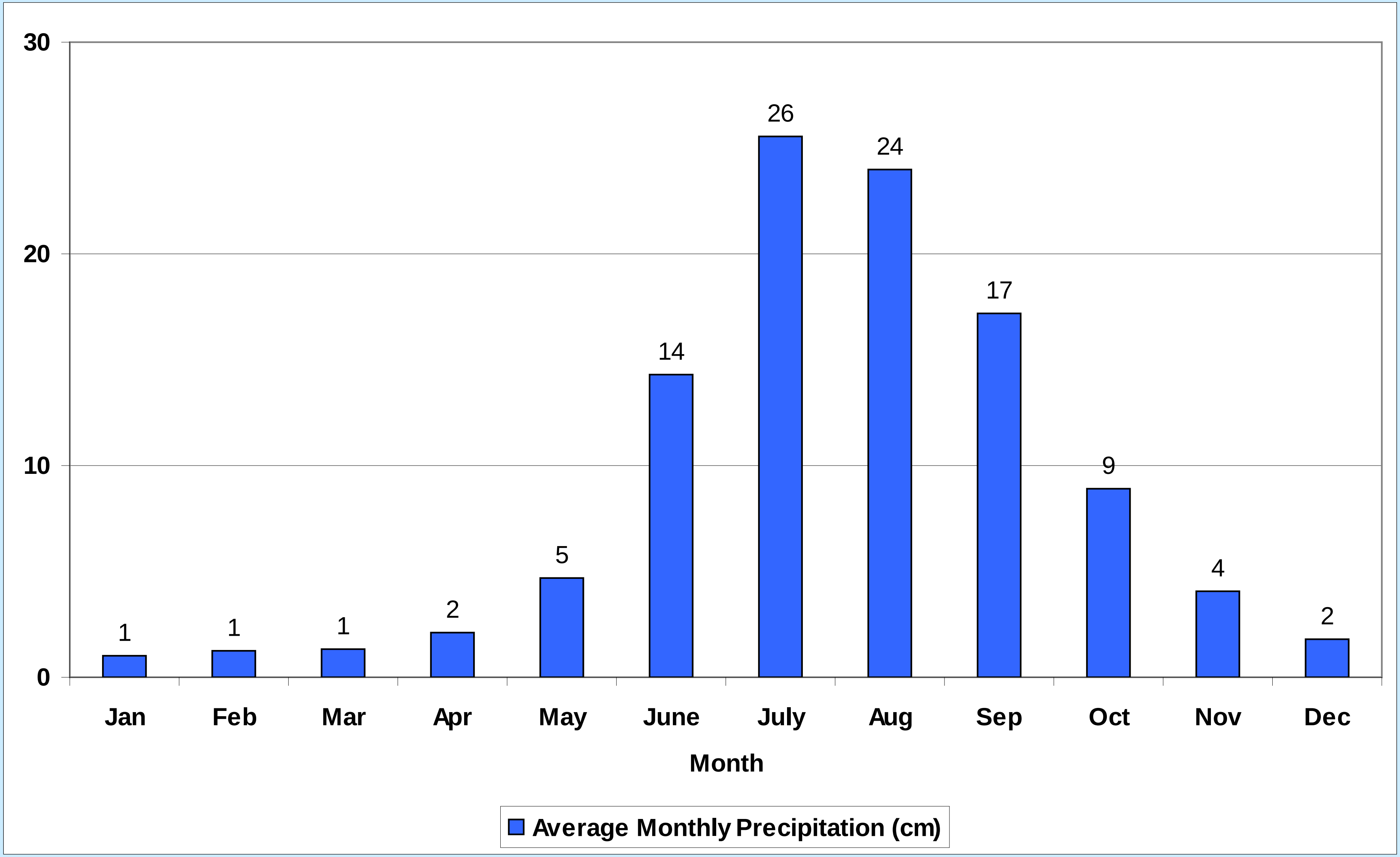
Weather Data

- Complete <u>daily</u> station-based weather data not available in India
- Use high-resolution ***modeled*** **(NCC)** daily weather at gridpoint level (1 degree x 1 degree)
- Source: Climatic Research Unit (CRU) and National Center for Atmospheric Research (NCAR)
- Daily average temperatures, total precipitation
- Gridpoint by day data aggregated to district level using inverse distance weighting (100 KM radius)

Distribution of daily mean temperatures, 1957-2000



Average monthly total precipitation, 1957-2000



Empirical approach

- 1. Estimate district-by-age group models for outcomes (log mortality rates, wages, labor supply, etc)

- (i) Include 15 separate variables for temperature to allow for nonlinearities; 12 variables for monthly precipitation
- $\Rightarrow$ *Also models with average daily temperature (single-index of exposure)*

- (ii) Include district-by-area fixed effects, year-by-area fixed effects, and region-specific time trends

- $\Rightarrow$ Exploit the substantial and presumably random year-to-year variation in temperature and precipitation distributions

Econometric model:

$$Y_{dt} = \sum_{j} \theta_j TMEAN_{dtj} + \sum_{m=1}^{12} \delta_m PREC_{dtm} + \alpha_d + \gamma_t + \lambda_r t^3 + \varepsilon_{dt}$$

- **TEMP**$_{\mathbf{dtj}}$ — Number of days in district d and year t where the daily mean temperature is in one of 15 bins that are 2° C wide-- < 10° C (50° F), > 36° C (96.8° F), and all 2° C wide bins in between
- **PREC**$_{\mathbf{dtm}}$ — Total monthly precipitation in district d, year t, month m
- → Only functional form restriction is that impact of temperature is constant within bins
- → Weight by population; cluster by district

Model with 'single-index' measure of temperature exposure:

$$Y_{dt} = \beta * ADT_{dt} + \sum_{m=1}^{12} \delta_m \mathrm{PREC}_{dtm} + \alpha_d + \gamma_t + \lambda_r t^3 + \varepsilon_{dt}$$

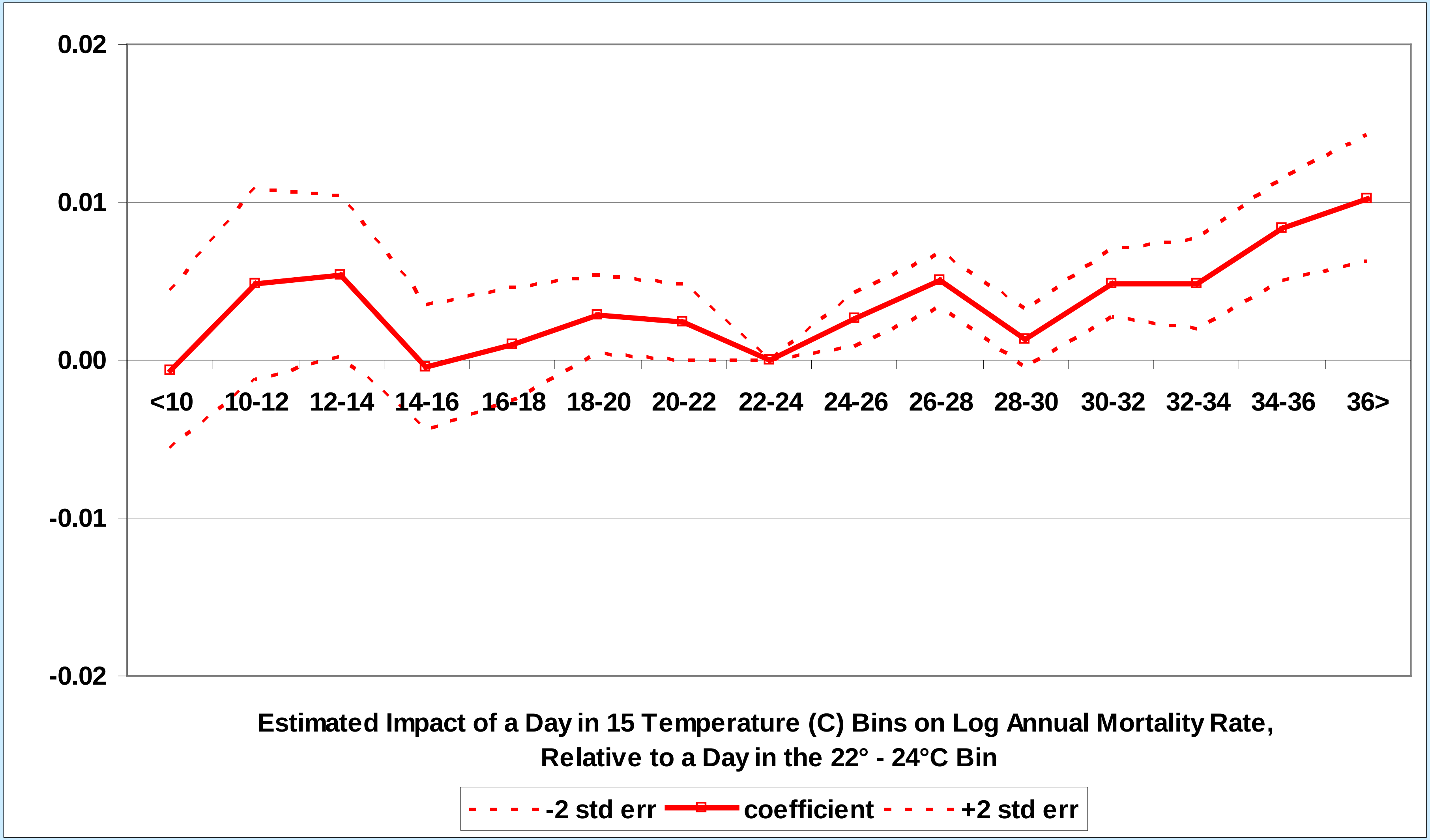
- **ADT_{dt}** — Average daily temperature in year t, district d
- **$PREC_{dtm}$** — Total monthly precipitation in district d, year t, month m
- → Weight by population; cluster by district

Results:

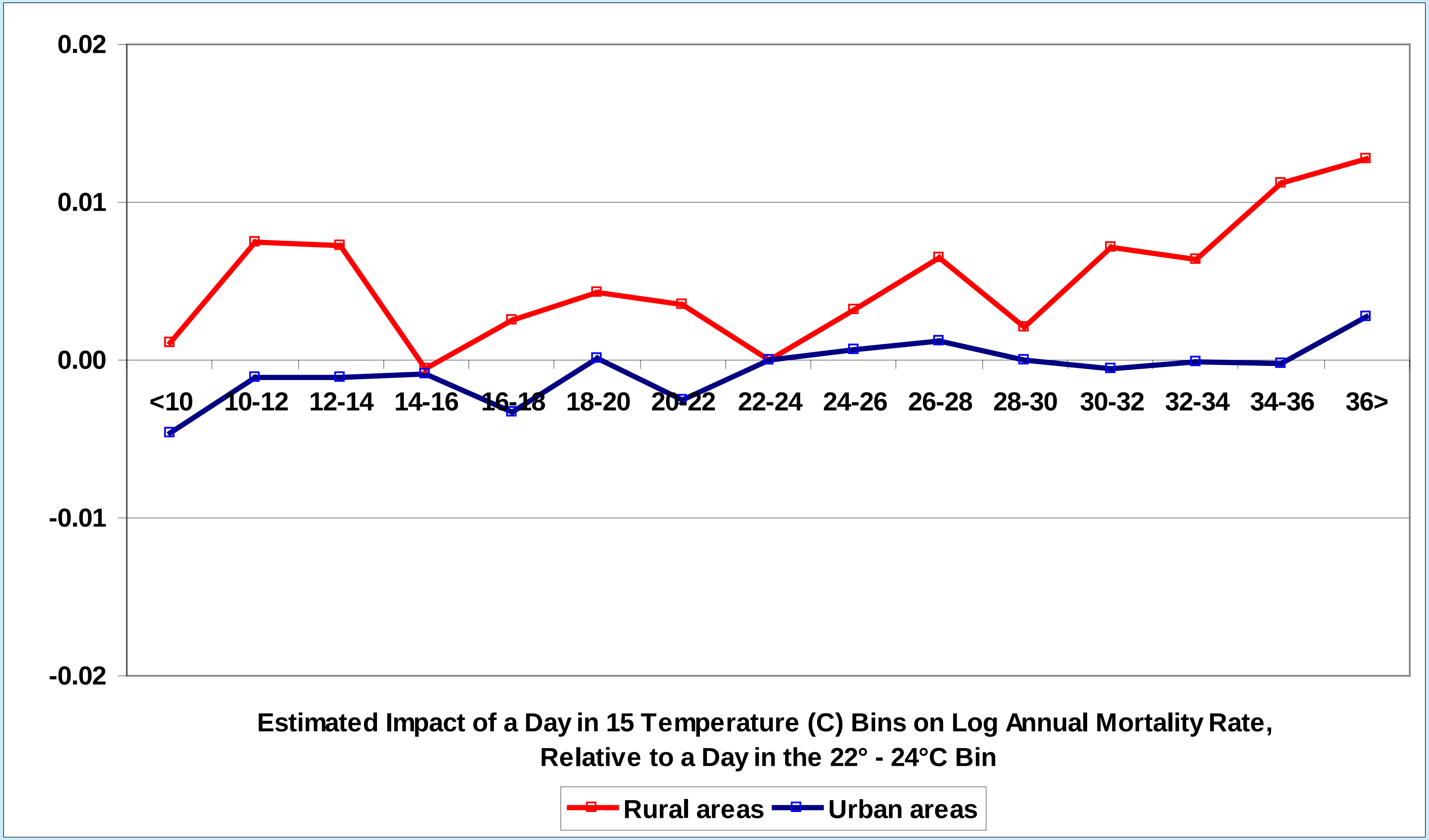
- **Impact on mortality rates**

- **Rural / urban differences**
- Impact on agricultural wages and labor supply
- Impact on agricultural yields and prices
- Impact on manufacturing wages
- Impact on bank credit disbursement

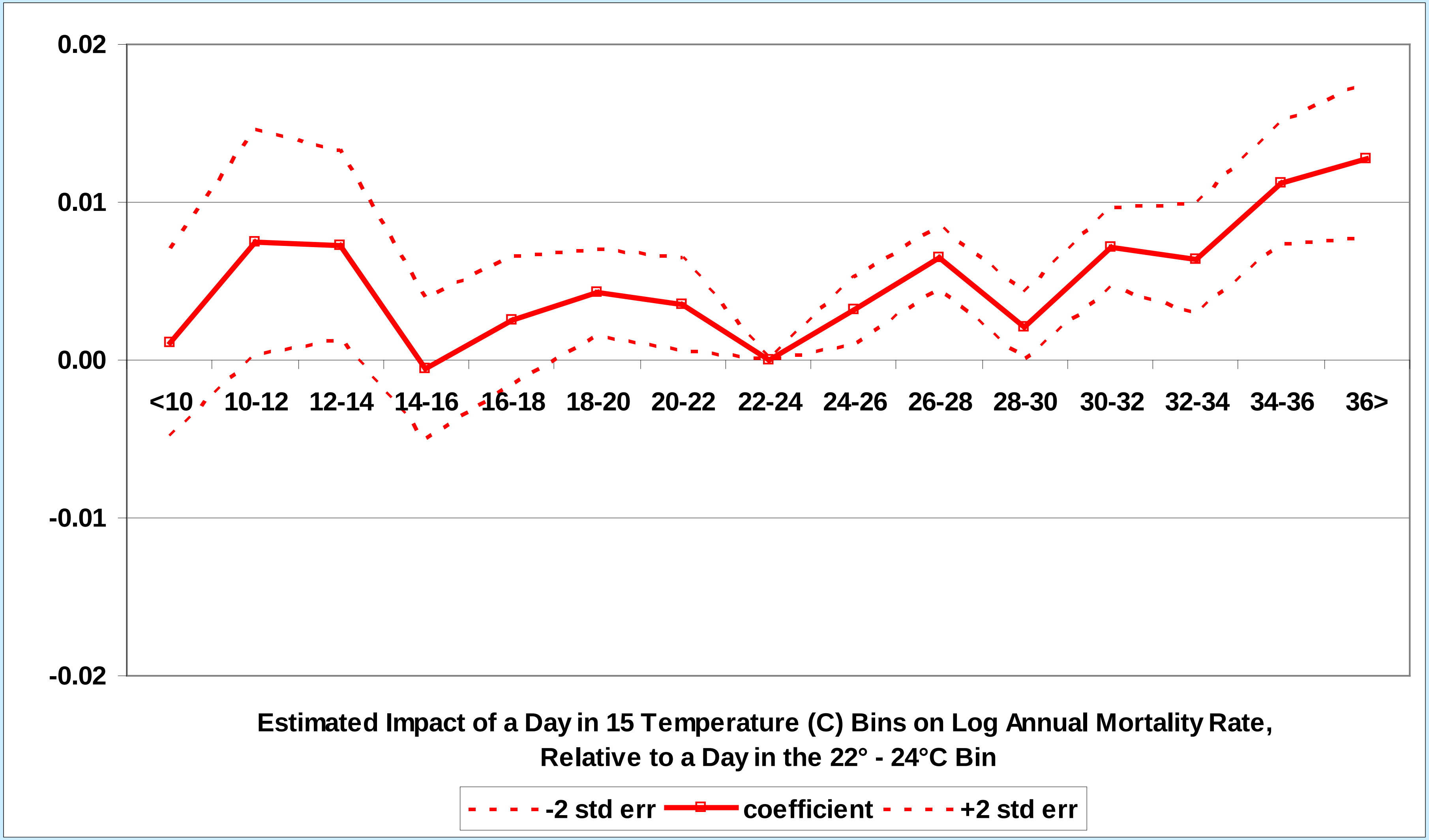
Estimated Response Function Between Temperature Exposure and Log Annual Mortality Rate (All Ages)



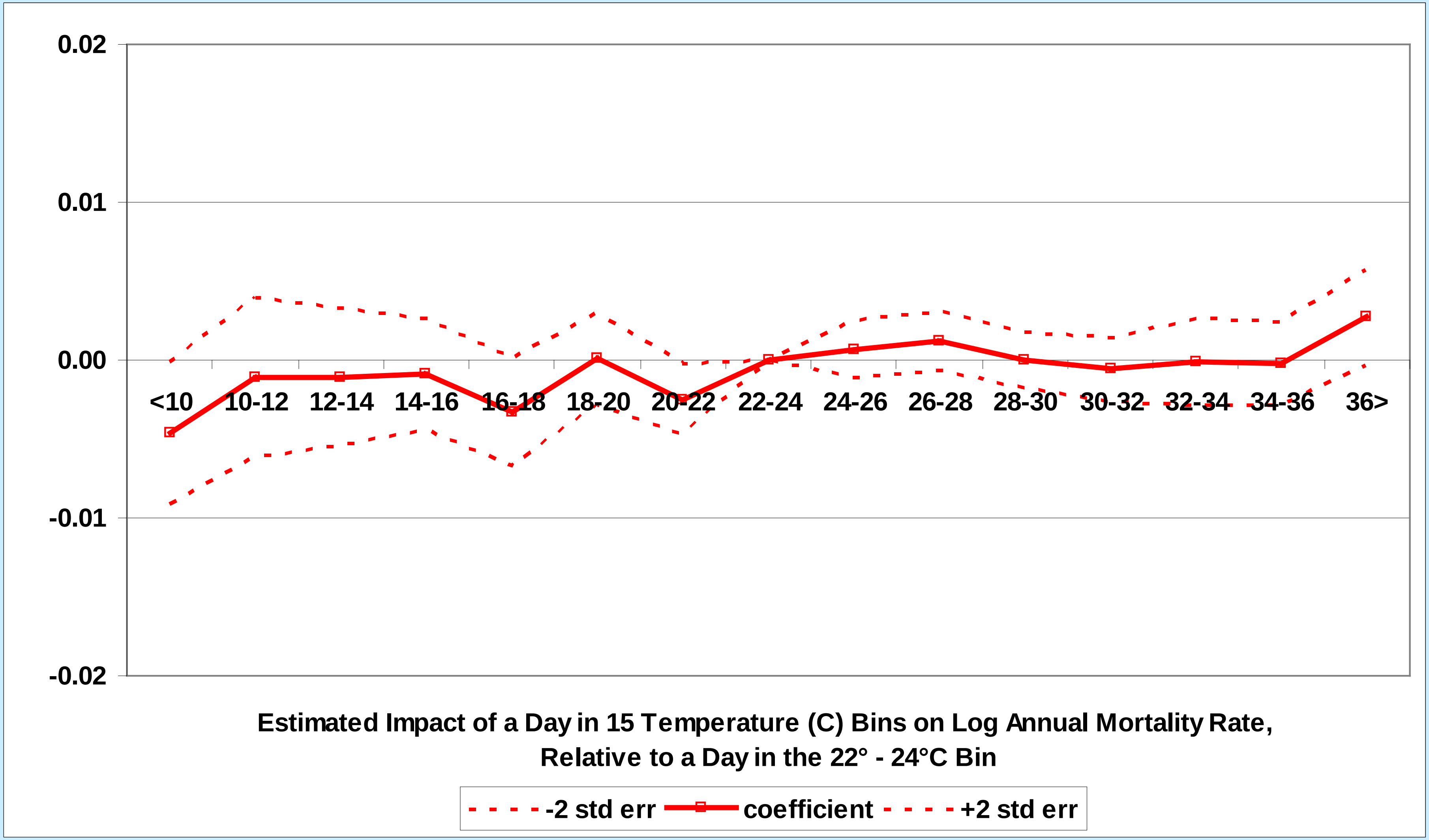
Estimated Response Function Between Temperature Exposure and Log Annual Mortality Rate (All Ages, By Rural/Urban Designation)



Estimated Response Function Between Temperature Exposure and Log Annual Mortality Rate (All Ages, Rural Areas)



Estimated Response Function Between Temperature Exposure and Log Annual Mortality Rate (All Ages, Urban Areas)



Estimates from models with single-index for temperature exposure

	(A) Average Daily Temperature			(B) Number of Days > 32C	
	(1) Rural areas	(2) Urban Areas	(3) Test of equality (p-value)	(1) Rural areas	(2) Urban Areas
Baseline (All Age)	0.120 (0.035)	-0.009 (0.033)	0.002	0.0042 (0.0011)	-0.0007 (0.0009)
Infants	0.144 (0.037)	0.009 (0.047)	0.041	0.0017 (0.0010)	-0.0009 (0.0010)
Age +1	0.106 (0.042)	-0.020 (0.032)	0.008	0.0051 (0.0011)	-0.0004 (0.0008)
Interacted with precipitations	0.129 (0.037)	-0.005 (0.033)	0.002	0.0035 (0.0011)	-0.0010 (0.0012)
Including lags	0.127 (0.048)	0.007 (0.047)	0.038	0.0042 (0.0016)	-0.0008 (0.0014)
Pre-1978 Only	0.140 (0.038)	0.004 (0.035)	0.004	0.0074 (0.0011)	0.0012 (0.0009)

What explains the rural / urban mortality response differential?

- **<u>Mechanisms:</u>** Why do the temperature shocks cause different mortality responses?

- *Different R/U impacts on wages and production*
- *Different R/U impacts on availability of smoothing mechanisms (bank credits from formal banking sector)*

- **<u>Mitigation:</u>** Can differential availability of health facilities and other infrastructures explain some of the R/U mortality difference?

- *Interaction of temperature effects with access measures to health facilities, etc*

Data on agricultural sector

- 1956-1987, annual, district-level (rural)
- From ‘World Bank India Agriculture’ data base
- Compiled from several data sources (entered from volumes)
- Covers only 13 large agricultural states
- We are working on extending some of the these series to 2000
- **Used by Guiteras (2008), Jayachandra (2006), World Bank Report #402 (Dinar et al. 1998)**

Data on agricultural sector

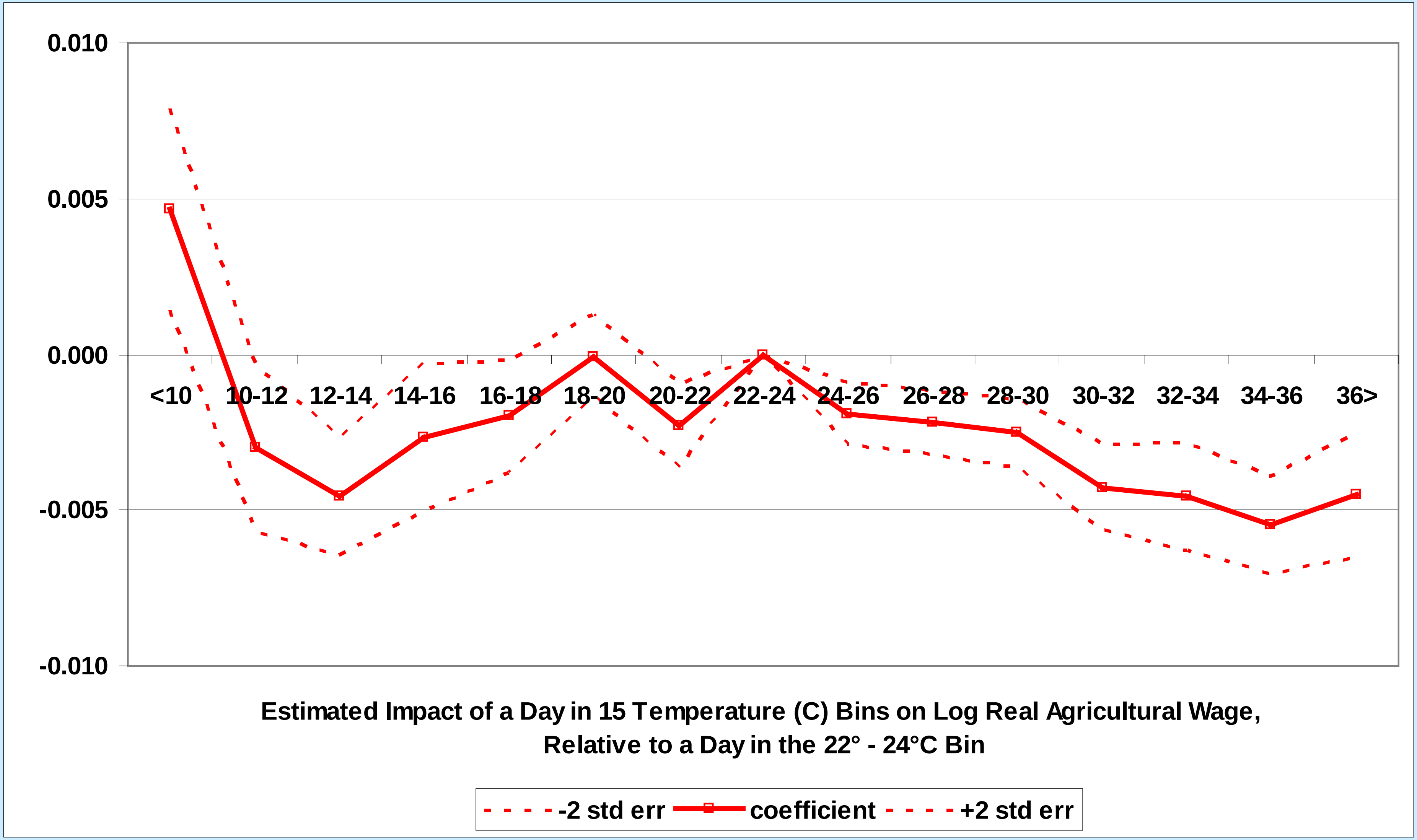
- **Key variables (district-level annual averages):**
- Daily agricultural wage (Source: IAW)

- Man-days worked by agricultural **laborers** (landless, working for wage) and **cultivators** (cultivate land that they either own or sharecrop), from decadal censuses

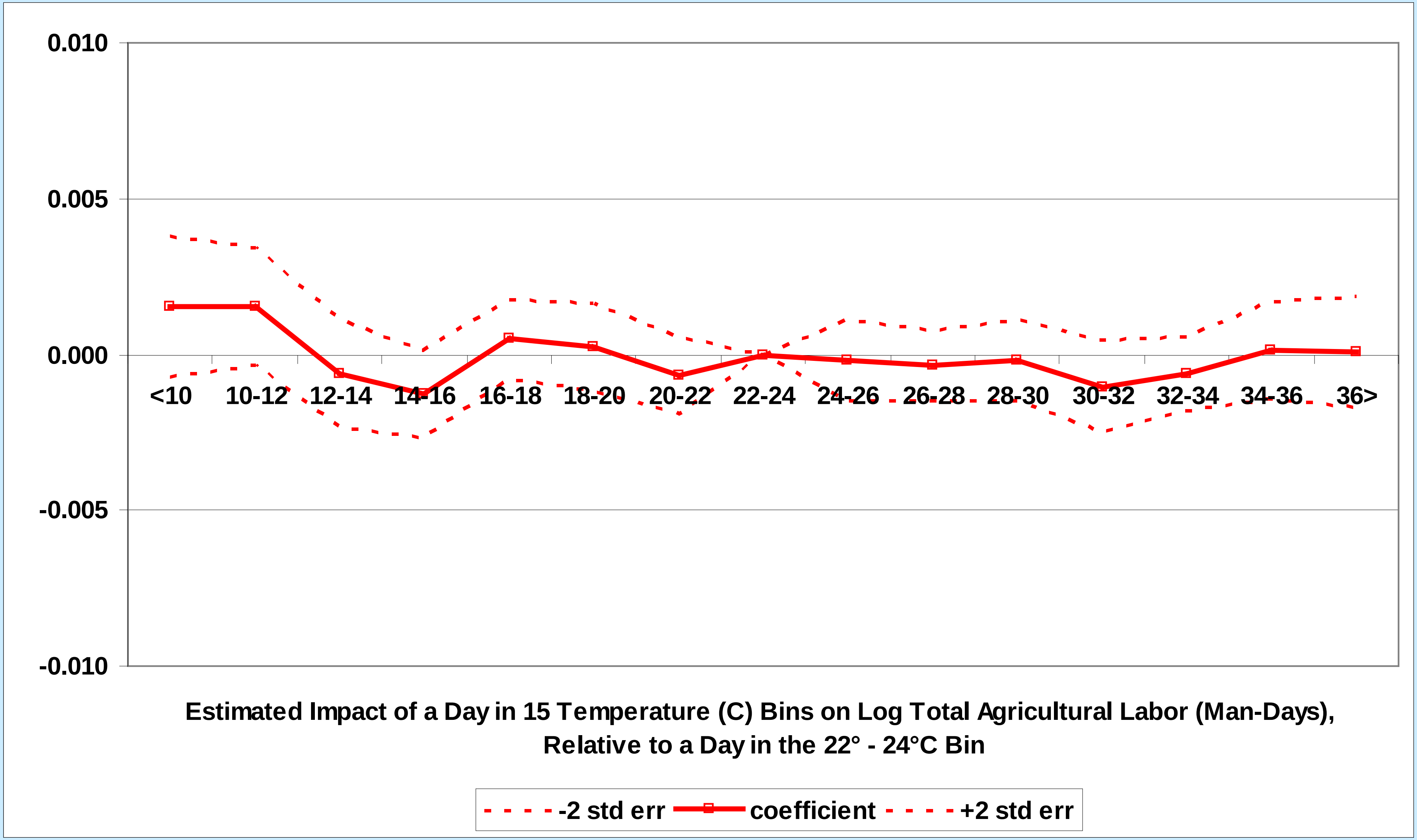
- Labor supply data are interpolated across census years
  - Labor supply results similar when using base years only

- 20 major crop yields and prices (Source: API and APPCI)

Estimated Response Function Between Temperature Exposure and Log Real Agricultural Wage Rate



Estimated Response Function Between Temperature Exposure and Log Total Agricultural Labor



Estimates from models with single-index for temperature exposure

	Impact of Average Daily Temperature: (1)	(2)
Log Agri. Wage	-0.085	---
	(0.015)	
Log Agri. Total Labor	-0.008	-0.060
	(0.009)	(0.042)
Log Agri. Wage Bill	-0.093	---
	(0.017)	
Log Agri. Laborers	-0.044	-0.025
	(0.023)	(0.073)
Log Agri. Cultivators	0.004	-0.008
	(0.011)	(0.045)
Years	1957-1986	1961, 1971, 1981

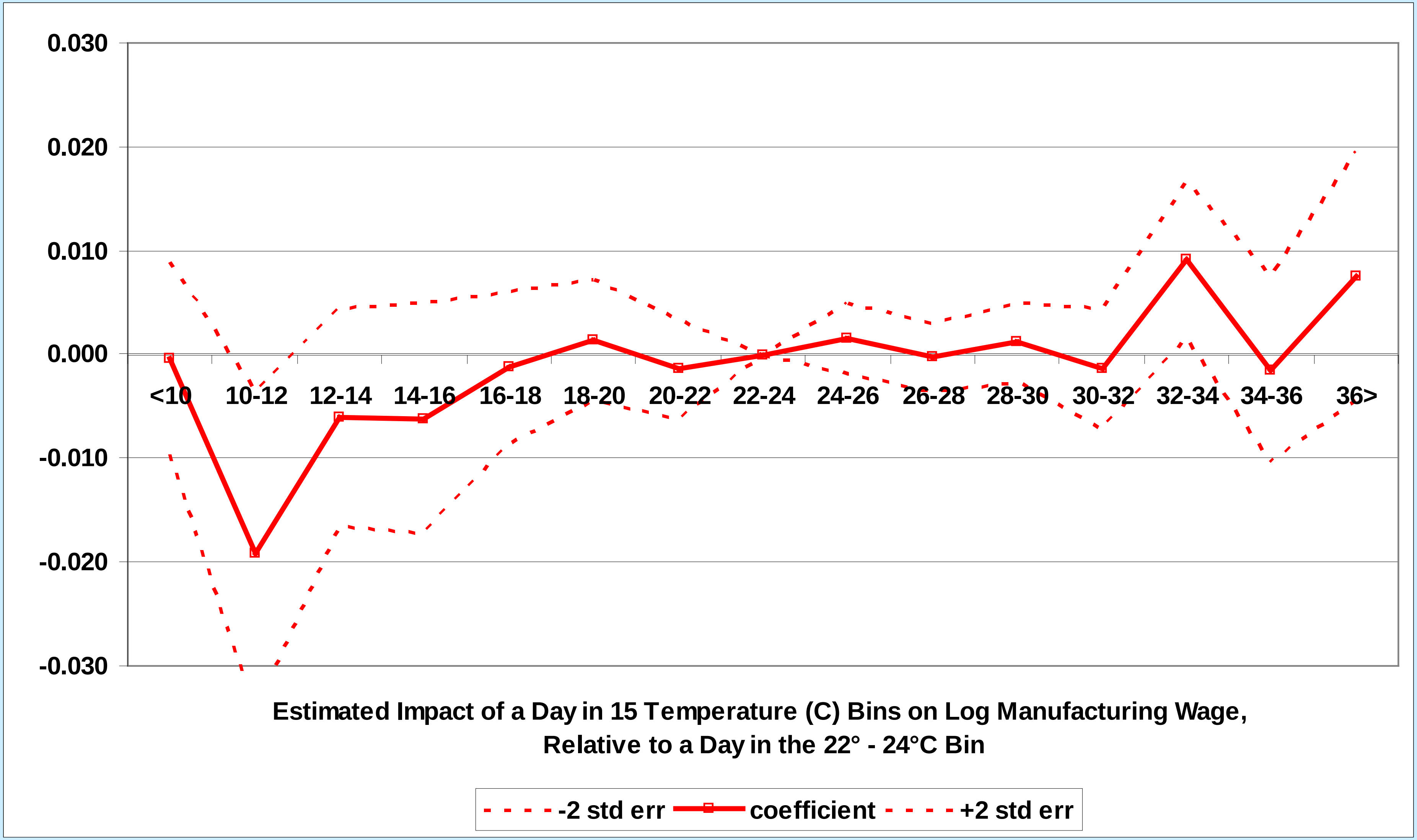
Estimates from models with single-index for temperature exposure

	Impact of Average Daily Temperature on:	
	Log Prices	Log Yield
	(1)	(2)
15 Crop Aggregate	0.031	-0.054
	(0.014)	(0.022)
Specific crops		
Wheat	0.064	-0.057
	(0.009)	(0.023)
Rice	0.014	-0.111
	(0.014)	(0.023)
Jowar	0.043	-0.100
	(0.008)	(0.037)

Results on ‘urban’ wage measures

- 1956-2000, from state-level publications (Annual Survey of Industries, Indian Labor Yearbook, etc)
- Per worker annual earnings in manufacturing industries
- More outcomes to come

Estimated Response Function Between Temperature Exposure and Log Manufacturing Wage



Effect of average daily temperature = 0.077 (0.040)

Data on bank deposits and credits

- District-level data for 1972-2002, taken from ‘Banking Statistics’ publications
- Data on bank offices, amount of deposits and credit disbursements
- Reported separately for urban and rural areas

Estimates from models with single-index for temperature exposure

	Effect of Average Daily Temperature:		
	Rural	**Urban**	**Equality (p-value)**
<u>Log Deposits Per Capita</u>			
w/o region cubic time trends	-0.095 (0.027)	0.008 (0.013)	0.001
with region cubic time trends	-0.039 (0.019)	-0.003 (0.010)	0.098
<u>Log Credit Disbursements Per Capita</u>			
w/o region cubic time trends	-0.161 (0.038)	0.019 (0.022)	0.001
with region cubic time trends	-0.042 (0.025)	0.030 (0.017)	0.011

Mitigation of temperature effects?

- District-level public goods data from 1991 Census records, by rural / urban designation
- Fraction of district population with access to hospitals, dispensaries, etc
- Create interactions of temperature effects with high-coverage districts
- Higher-coverage mitigates temperature effect, but estimate imprecise

Results on mitigation (rural areas only)

	Average temperature effect	Interacted with 'high' coverage district
Access to Hospital (25th Percentile = 0.02)	0.137 (0.062)	-0.020 (0.053)
Access to Dispensary (25th Percentile = 0.04)	0.143 (0.056)	-0.030 (0.054)

Projected climate change impacts

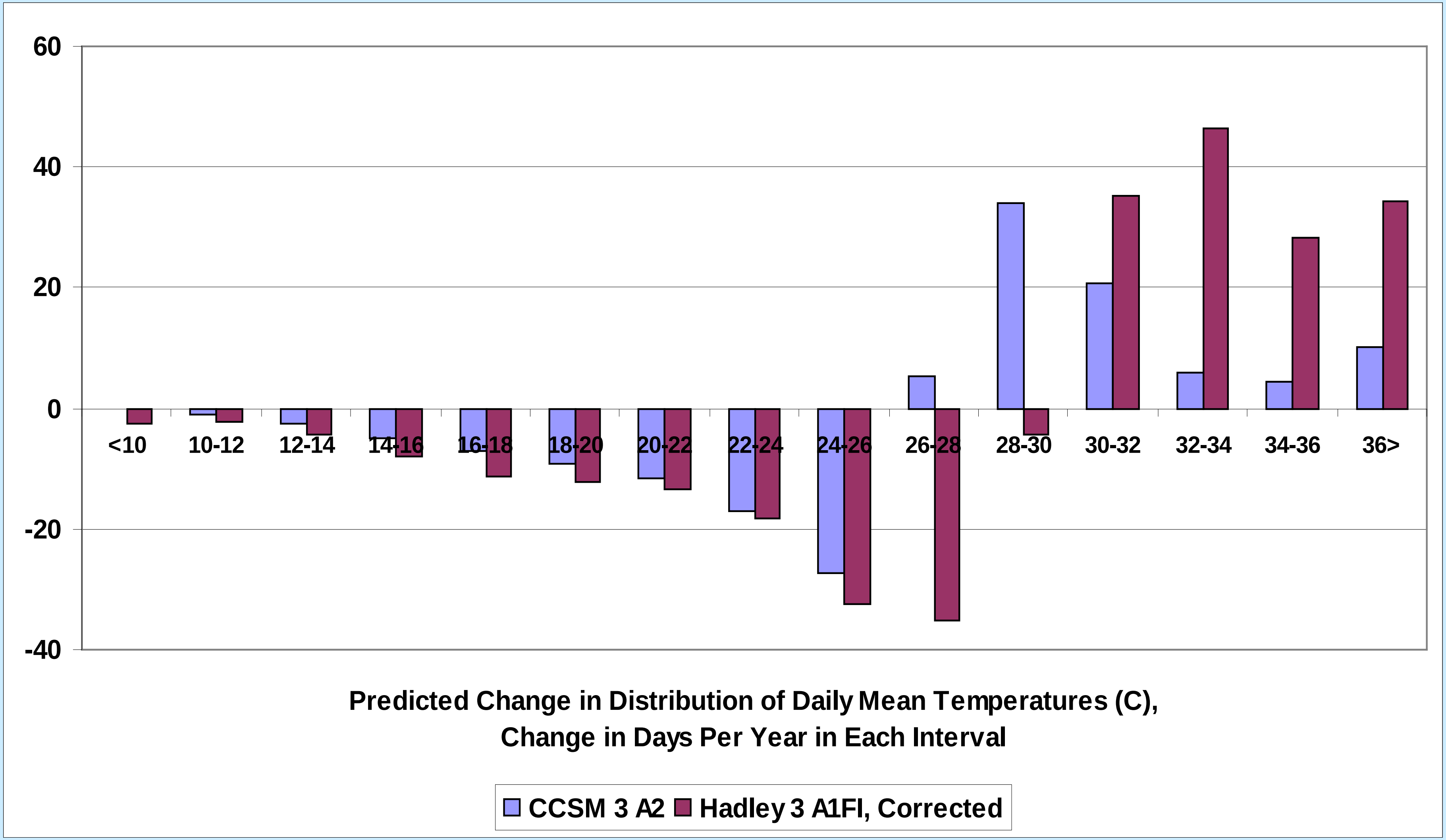
- Use empirical estimates of response functions
- Project on predicted change in number of days in each per temperature bins and predicted change in monthly precipitation
- National impact calculated as population-weighted average of district-level impact:

$$\sum_{j}(\hat{\theta}_j \bullet \Delta TMEAN_{dj}) + \sum_{m=1}^{12}(\hat{\delta}_m \bullet \Delta PREC_{dm})$$

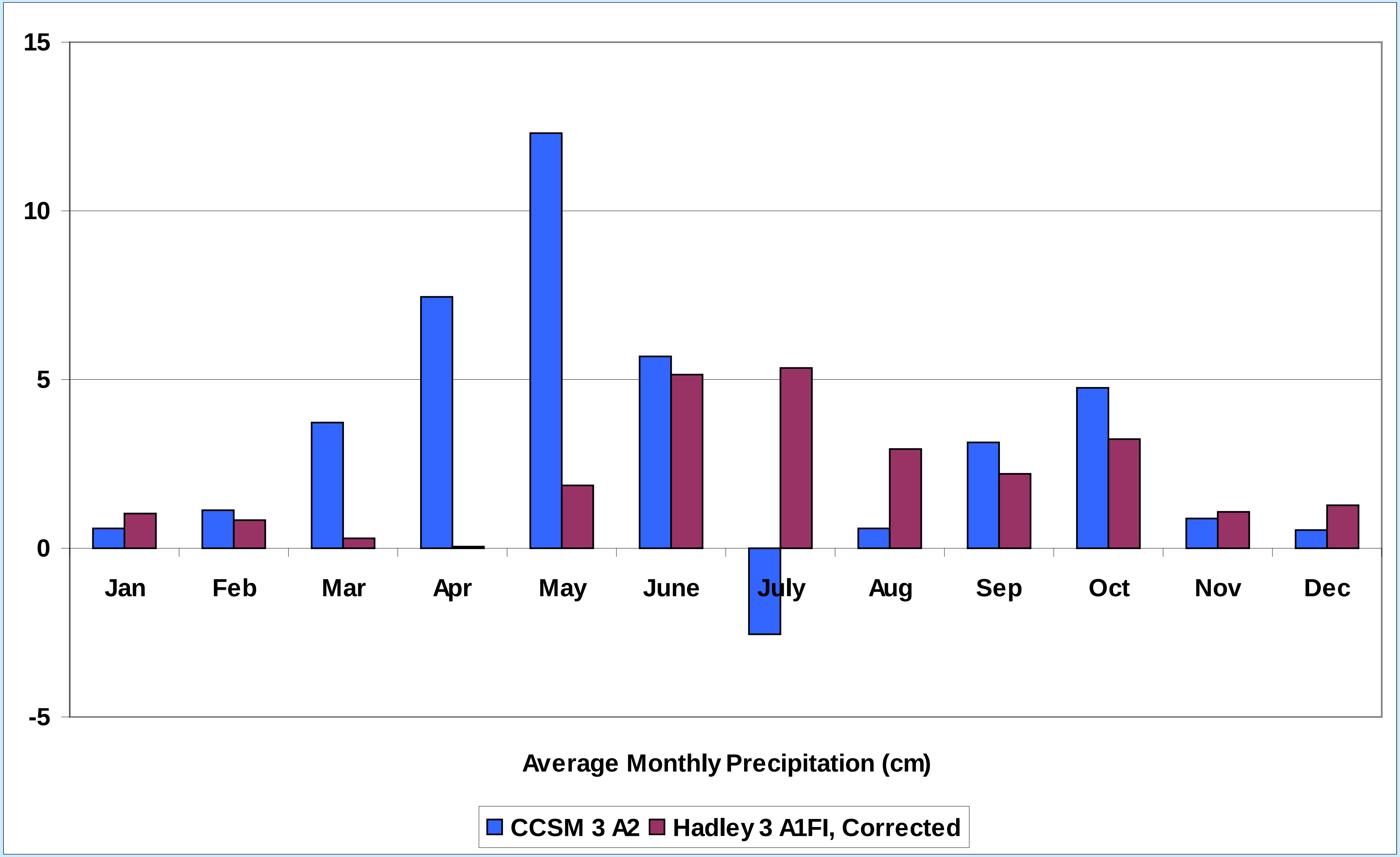
Climate Change Predictions

- Hadley 3 A1FI, NCAR CCSM 3 A2
- Both are high emissions / “business as usual” scenario (predict largest increases in global temperatures)
- Daily predictions of minimum and maximum temperatures and precipitation for 1990-2099 (2000-2099 for CCSM)
- Hadley 3 predictions corrected for model error by comparing 1990-2000 predictions with actual weather
- Grid points spaced by 2.5° (latitude) x 3.75° (longitude) in Hadley 3, and 1.4° (latitude) x 1.4° (longitude) in CCSM

Predicted change in annual distribution of daily temperatures (2070-2099 and 1957-2000)



Predicted change in monthly precipitations, (2070-2099 and 1957-2000)



Predicted Impacts of Climate Change on All-Age Annual Mortality Rates (%)

	Impact of Change in Days with Temperature: <16C (1a)	16C-32C (1b)	>32C (1c)	Total Temperature Impact (2)
A. Based on Hadley 3, A1FI				
Pooled	-0.034	-0.140	0.731	0.557
	(0.033)	(0.048)	(0.134)	(0.138)
Rural Areas	-0.060	-0.167	0.931	0.703
	(0.040)	(0.056)	(0.161)	(0.166)
Urban Areas	0.039	-0.009	0.094	0.124
	(0.034)	(0.059)	(0.112)	(0.110)
B. Based on CCSM3, A2				
Pooled	-0.018	0.028	0.166	0.176
	(0.014)	(0.043)	(0.030)	(0.064)
Rural Areas	-0.027	0.053	0.212	0.238
	(0.017)	(0.051)	(0.037)	(0.076)
Urban Areas	0.010	0.026	0.031	0.067
	(0.014)	(0.043)	(0.024)	(0.056)

Predicted Impacts of Climate Change on All-Age Annual Mortality Rates (%), (continued)

	Total Temperature Impact (2)	Total Precipitation Impact (3)	Temperature and Precipitation Impact (4)
A. Based on Hadley 3, A1FI			
Pooled	0.557	0.008	0.564
	(0.138)	(0.010)	(0.142)
Rural Areas	0.703	0.008	0.711
	(0.166)	(0.012)	(0.171)
Urban Areas	0.124	-0.006	0.118
	(0.110)	(0.009)	(0.113)
B. Based on CCSM3, A2			
Pooled	0.176	-0.076	0.099
	(0.064)	(0.037)	(0.084)
Rural Areas	0.238	-0.082	0.155
	(0.076)	(0.042)	(0.098)
Urban Areas	0.067	-0.097	-0.030
	(0.056)	(0.045)	(0.085)

What is next?

- More data collection (extend agricultural wage series to 2000, assess reliability of VSI data, mortality counts by sex, age category (SRS), other health outcomes (NFHS), etc)

- More analysis (impact of within-year timing of exposure, impact of ‘heat waves’, impacts by growing season)

- Put all the pieces together and assess importance of various channels (wage, bank credit, etc) in explaining the R/U mortality differential

- Expand analysis to other health outcomes, infant health particularly important to study

Conclusions

- First large-scale study of the impact of weather shocks on mortality and adaptations for a developing country that we are aware of

- It is based on the finest geographical data available on mortality for India over the period 1957-2000, augmented with rich high-frequency data on historical daily weather

- Clear evidence that extreme temperature causes increases in mortality in <u>rural</u> areas

- <u>One</u> additional day with a mean temperature above 32°C, relative to a day with a mean temperature in the 22°-24°C range, <u>increases the annual mortality rate by roughly 0.8%</u>

- ***Large effect ($\approx$ 10 times larger than US effect)***

Conclusions

- In rural areas, extreme temperatures lead to <u>lower real incomes</u> (agricultural wages, little change in labor supply and higher crop prices)

- Also decline in bank credit disbursements

- In urban areas, extreme temperatures do not appear to affect manufacturing wages, and if anything, *increase* bank credit disbursements

- Climate change projections lead to very large predicted increase in mortality (8% - 56%), but these are the upper-bounds

More on vital statistics data

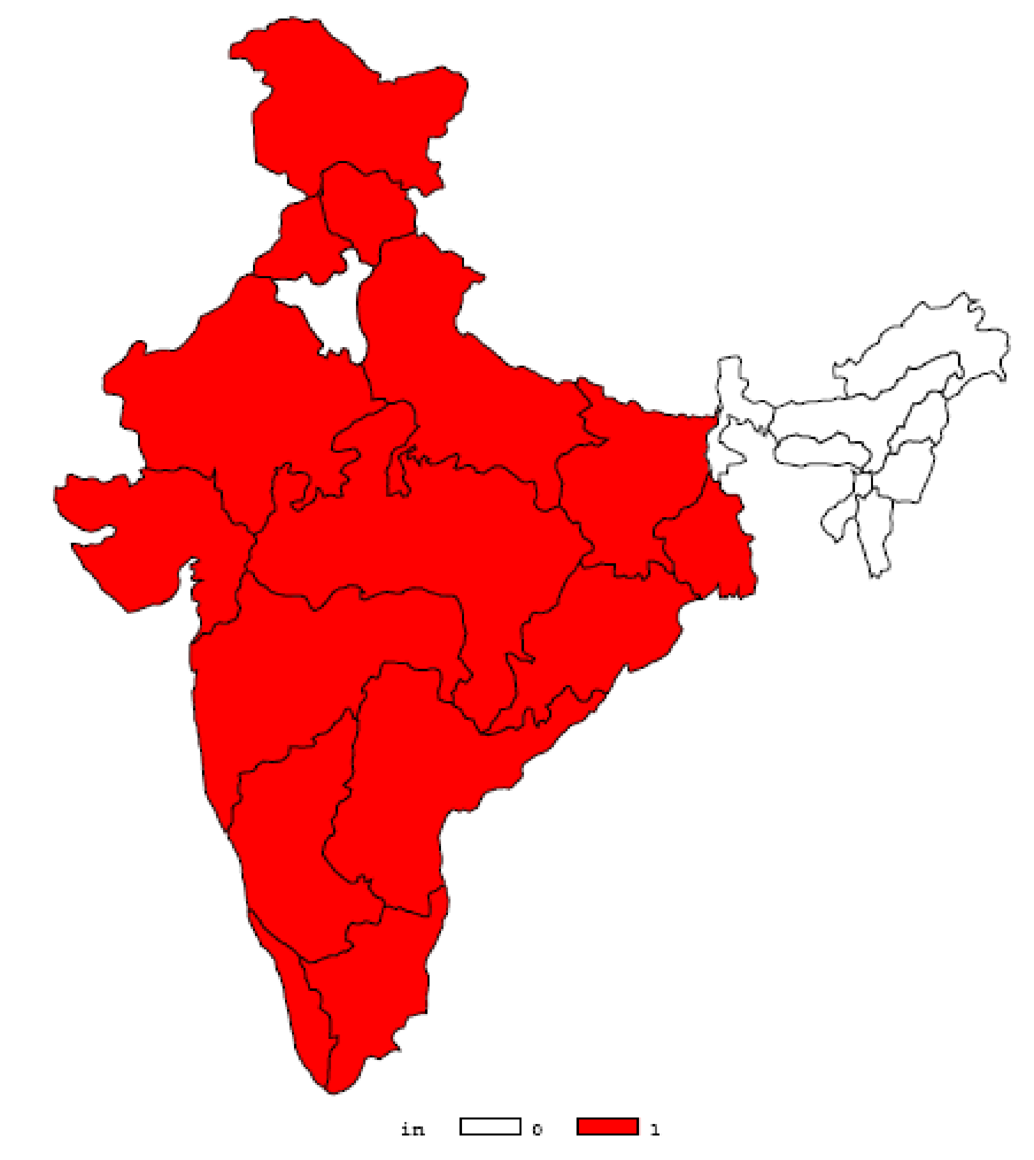
- The VS data is based on the official Civil Registration System (CRS). Registration is mandatory. Each locality (village or urban ward/block) has an official registry on which all vital events are meant to be recorded. Each month every locality is meant to send a copy of all of the additions to this registry to the national Chief Registrar

- Under-registration occurs for two reasons: First, some localities don't send in their reports. Nationally, 77% of localities submitted in 1995, and this was similar by U/R. The non-submission problem is confined to a handful of states (the worst areas, the urban bits of Andrah Pradesh and Uttar Pradesh, had only 27% submission in 95). Second, the reports that the localities do send are likely to miss many of the vital events.

More on vital statistics data

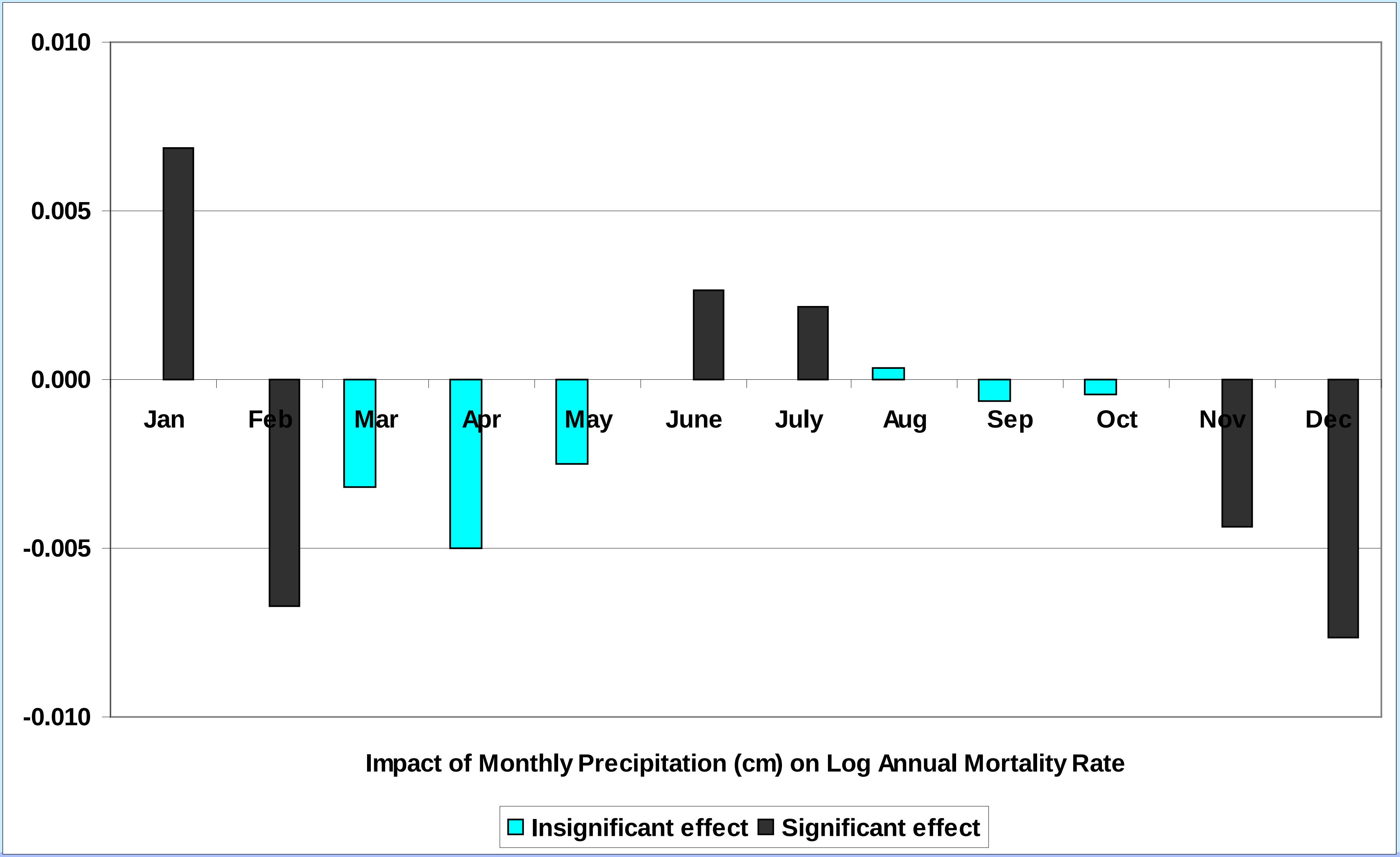
- The annual Sample Registration Survey (SRS) does a very reliable job of counting all vital events occurring to a random sample of families. The data from this survey is then commonly used to assess how bad the under-reporting problem in the CRS is.
- From this comparison (in 1995) the following is relevant:
- (a) On aggregate, only 47% of deaths are registered, but this varies a great deal by state (3 big states have over 80% registration of deaths; Assam, Bihar, Rajasthan, Uttar Pradesh and West Bengal all have around 25% registration).
- (b) Infant mortality suffers from even worse under registration
- (c) Under-registration is much worse in rural areas than in urban

Included and Excluded States in Vital Stats Main Sample

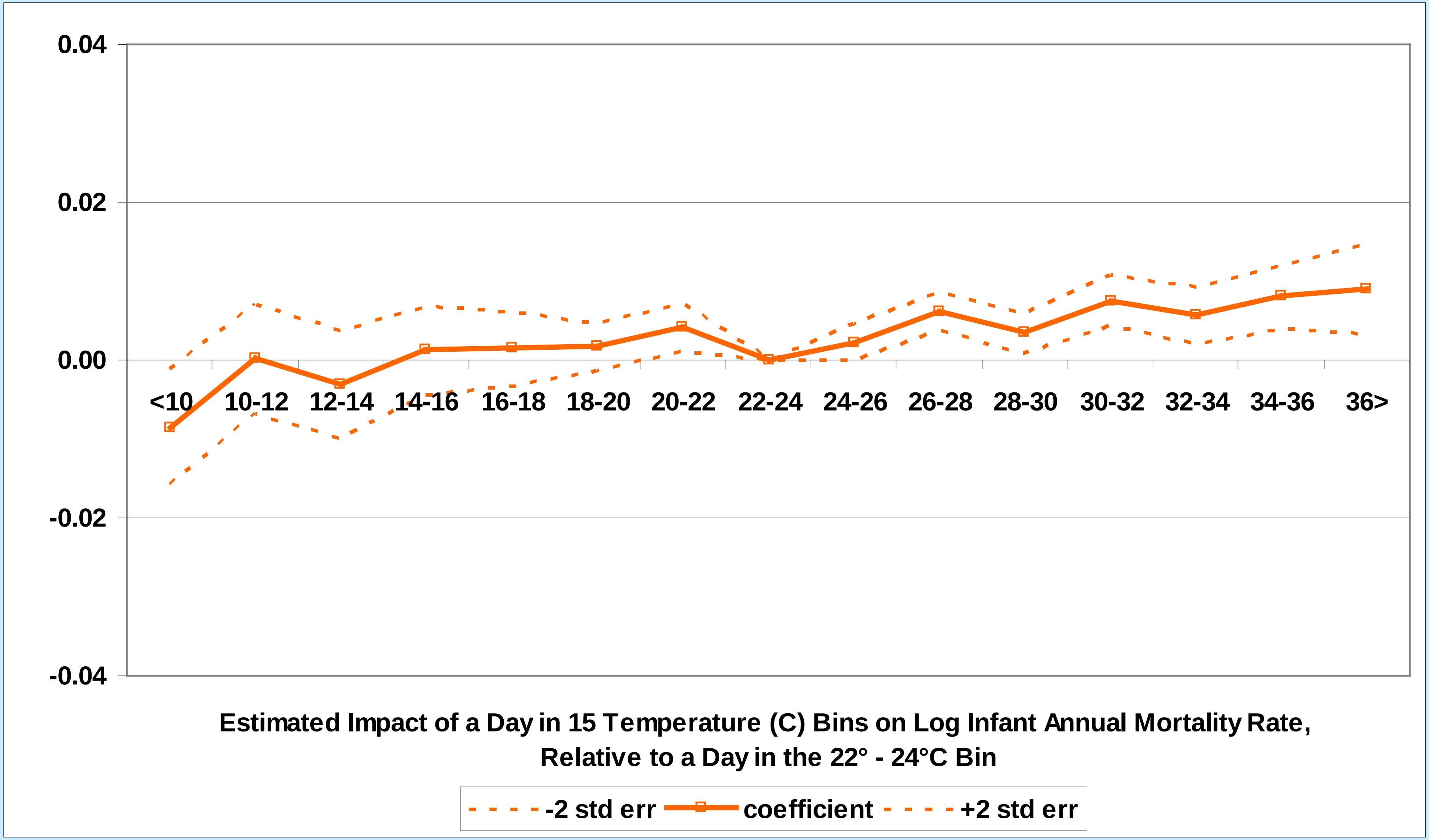


<u>Excluded:</u> Assam, Arunachal Pradesh, Haryana, Manipur, Meghalaya, Mizoram, Nagaland, Sikkim, Tripura

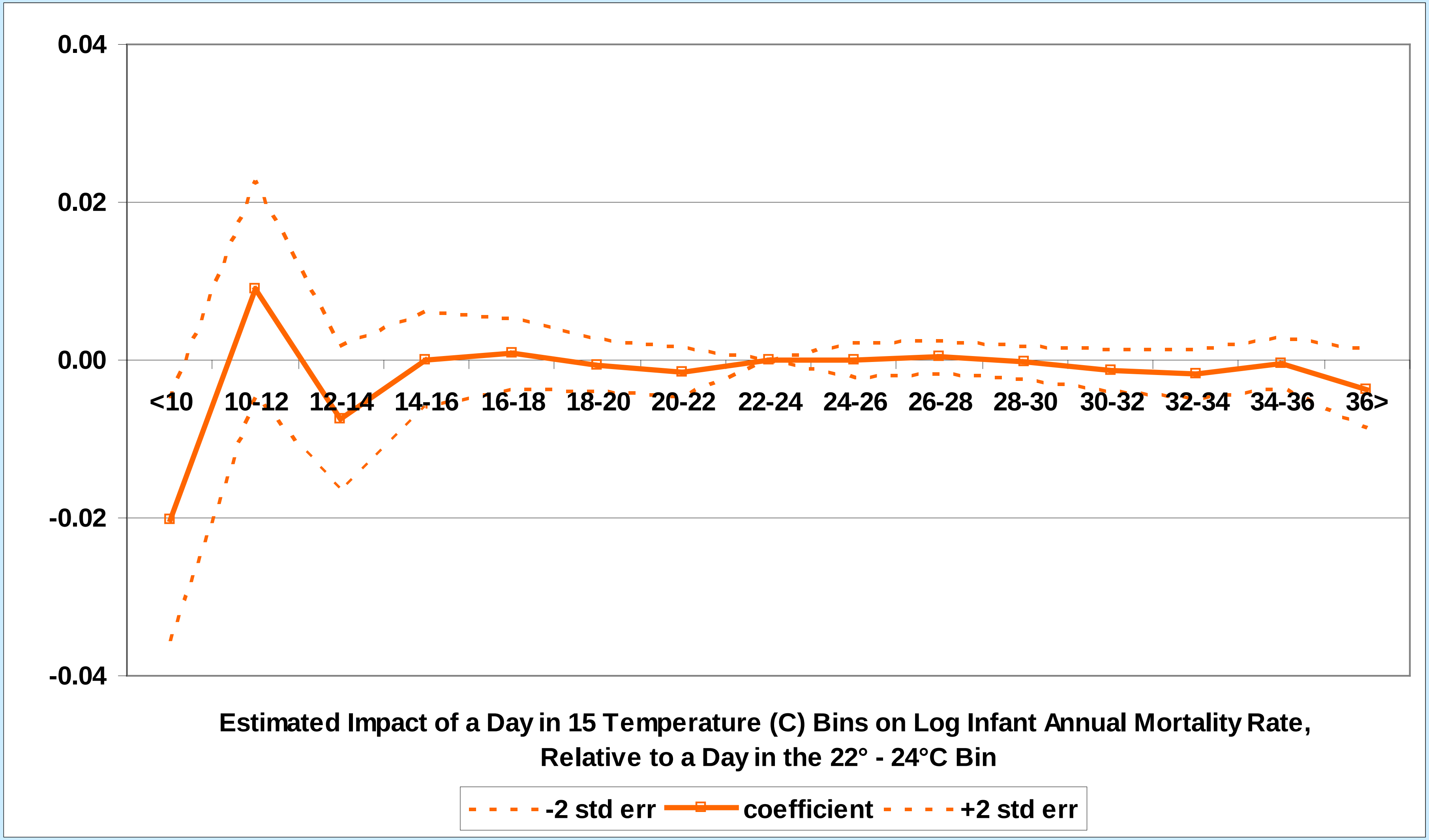
Estimated Effect of Monthly Precipitation on Log Annual Mortality Rate (All Ages)



Estimated Response Function Between Temperature Exposure and Log Annual Mortality Rate (Infants, Rural Areas)



Estimated Response Function Between Temperature Exposure and Log Annual Mortality Rate (Infants, Urban Areas)



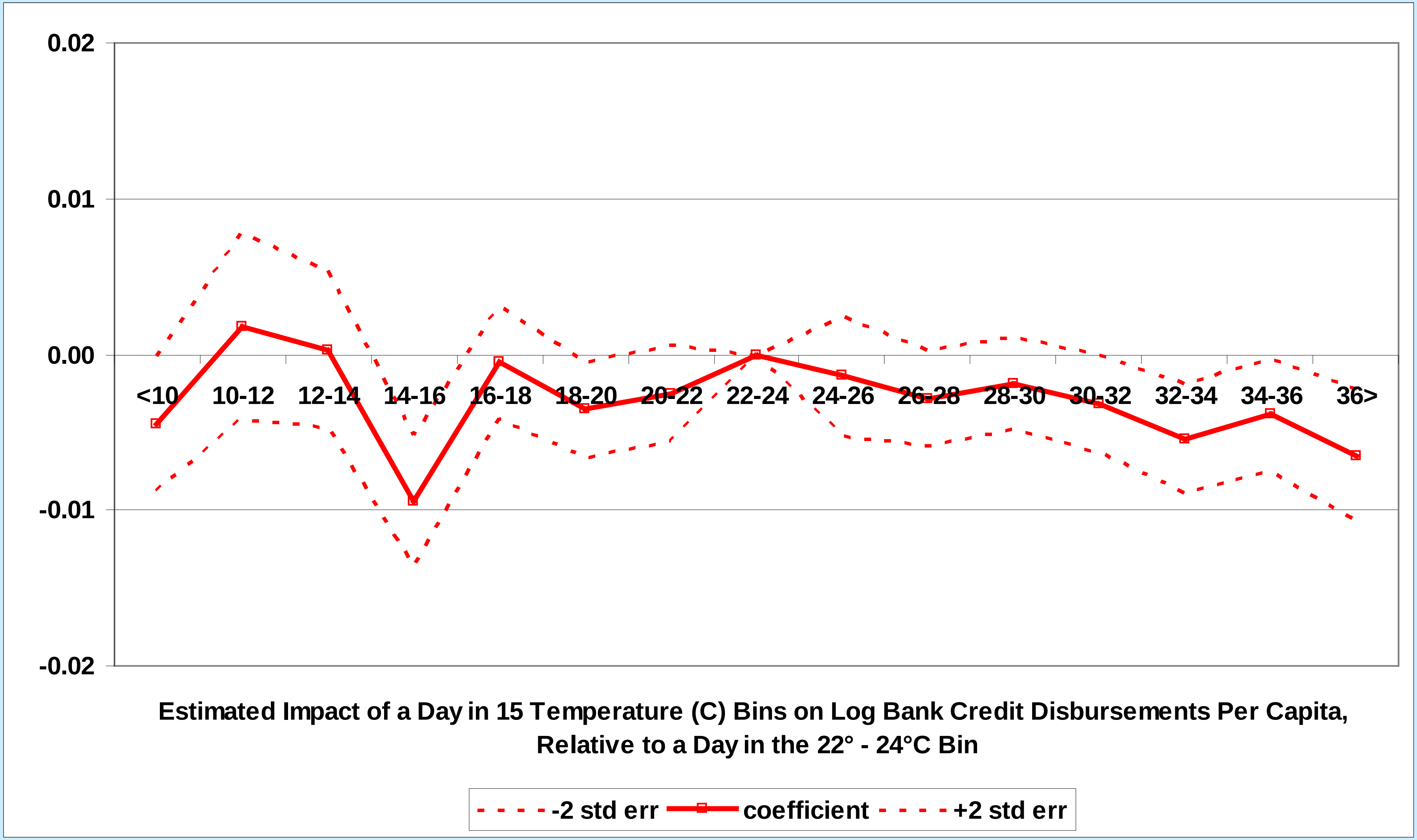
Seasonal temperature effects:

	(A) Average Daily Temperature		
	(1) Rural areas	(2) Urban Areas	(3) Test of equality (p-value)
Baseline (All Age)	0.120	-0.009	0.002
	(0.035)	(0.033)	
Winter	0.052	-0.006	0.004
	(0.015)	(0.017)	
Spring	0.064	0.001	0.001
	(0.016)	(0.013)	
Summer	0.100	-0.001	0.001
	(0.018)	(0.018)	
Fall	-0.082	0.002	0.001
	(0.015)	(0.013)	

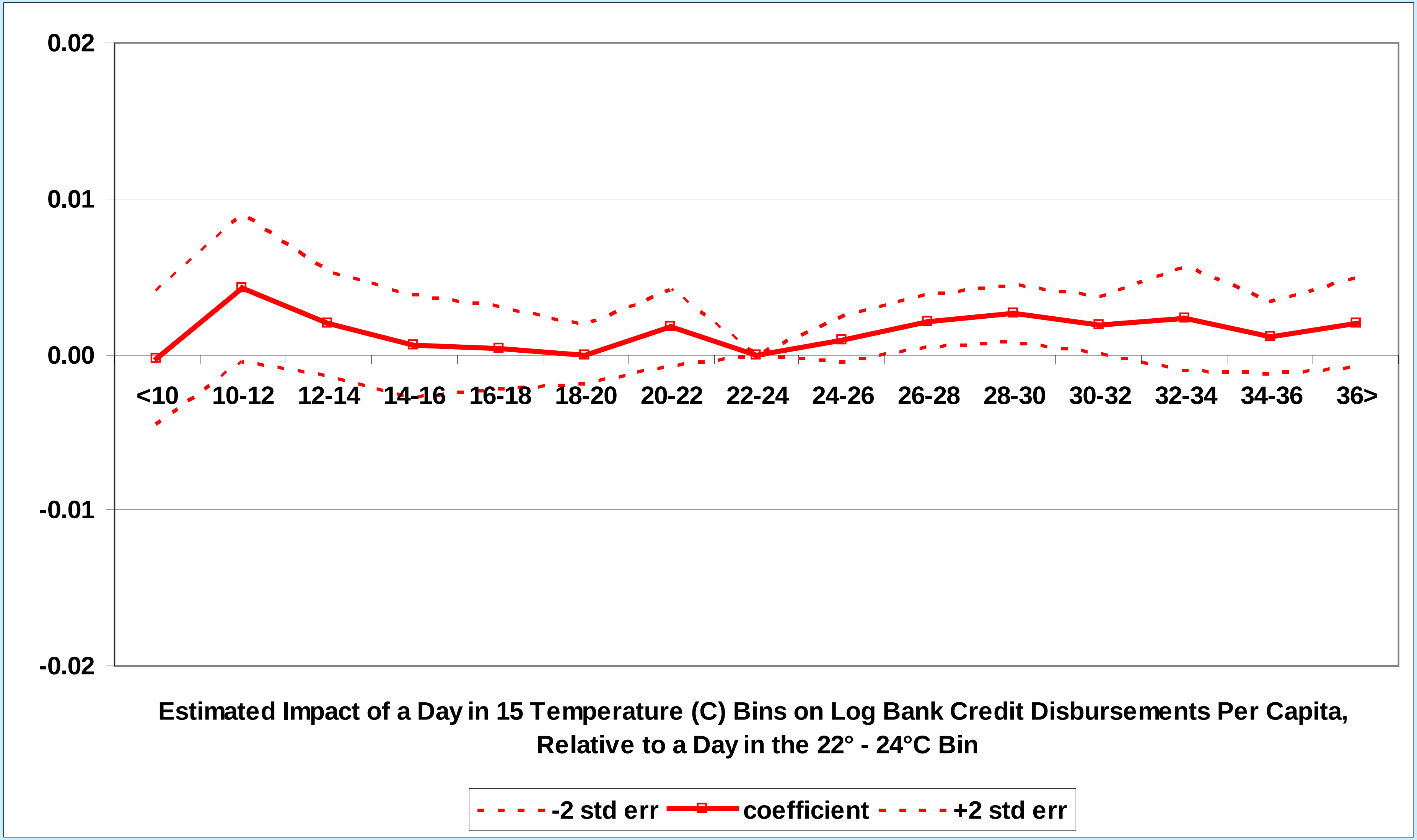
Sample means of agricultural variables:

	Real Ag. Wage (Rs / Day)	Total Labor (Mil. Man-Days)	Agricultural Laborers (Mil. Man-Days)	Cultivators (Mil. Man-Days)
All States	6.88	20,839*	5,826*	14,501*
Andhra Pradesh	6.33	1,545	589	956
Bihar	6.45	2,197	806	1,391
Gujurat	7.82	820	212	608
Madhya Pradesh	5.34	2,057	486	1,571
Madras	5.80	1,721	633	1,088
Maharashtra	6.00	2,142	739	1,403
Mysore	6.35	1,100	301	799
Orissa	5.46	1,061	302	760
Punjab	12.67	981	269	712
Rajasthan	9.58	1,122	94	1,029
Uttar Pradesh	6.55	3,990	788	3,202
West Bengal	7.94	1,590	608	982

Estimated Response Function Between Temperature Exposure and Log Bank Credits Disbursed Per Capita (Rural Areas)



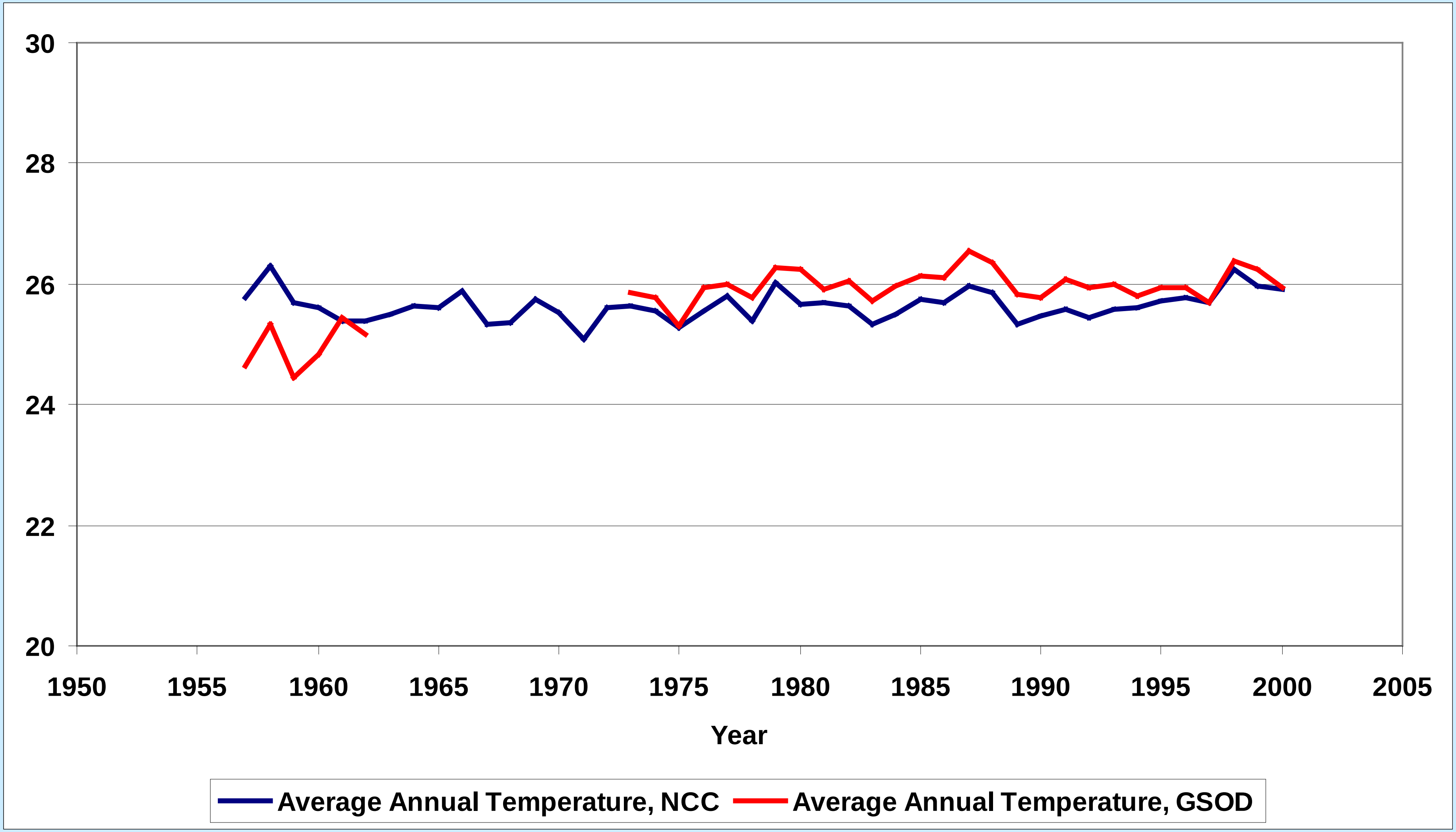
Estimated Response Function Between Temperature Exposure and Log Bank Credits Per Capita (Urban Areas)



Global Summary of the Day

- Daily-level weather data compiled and maintained by NCDC
- Records from about 150 monitors in India
- Main problem is that data rarely continuously available
- No records at all for 1963-1972
- No station with complete daily record for a year between 1987-1996
- In other years, 3-9 stations have complete daily record for a year

NCC / GSOD Comparison



Manipulation of the Raw VS Data:

- Correcting for district splits: India’s district borders have changed in the 1957-2001 period. These changes are documented in the Indian Administrative Atlas, 1872-2001

- The vast majority of changes are pure district splits, where a given district (referred to here as ‘1961 districts’) splits into two or more smaller districts (referred to here as ‘post-split districts’). We have corrected for these by aggregating vital statistics over the two or more post-split districts.

Measurement error

- Mortality data in India is likely underreported

- Under-reports may be more prevalent in rural areas and in years with extreme weather

- This means there is a <u>negative</u> correlation between measurement errors in dep variable and regressors of interest (temperature bins)

- Leads to attenuation of the impact of regressor of interest

- Simple illustration:

$$y_i = \alpha + \beta x_i + \varepsilon_i$$

$$y_i^o = y_i + u_i \qquad E[y_i u_i] = 0 \qquad E[x_i u_i] = 0 \qquad x_i^o = x_i$$

$$\Rightarrow y_i^o = \alpha + \beta x_i + (\varepsilon_i + u_i)$$

$$\Rightarrow \text{plim}\hat{\beta} = \frac{Cov(y_i^o, x_i)}{V(x_i)} = \beta + \frac{Cov(u_i, x_i)}{V(x_i)}$$

Agricultural Wages Data in E-M file

- Taken from Agricultural Wages in India
- WAGE=Weighted (by month) labor cost. June and August were weighted more heavily than other months because of the high intensity of field work during those months.
- AWI data not interpolated
- The AWI provides monthly averages of daily wages of unskilled casual laborers. The wage is expected to reflect both cash payment and monetary equivalent of the payment made in kind. This wage is either reported as a consolidated wage rate for “field labor”, or reported separately for different agricultural operations, such as “ploughing”, “sowing”, “weeding”, “reaping and harvesting”, along with wages for “other agricultural labor” and “herdsman”.

Background: Physiological response to extreme temperatures

- Body has a natural temperature regulation system
- Exposure to high and low temperatures triggers an increase in the heart rate, sweating in hot weather, shivering in cold

- **Heat stress:**
- Associated with increased deaths, primarily due to cardiovascular and respiratory diseases
- Issue of short-term mortality displacement (‘harvesting’)

- **Cold stress:**
- Causes cardiovascular stress due to changes in blood pressure, clots, and viscosity
- Issue of delayed impacts (Deschenes and Moretti 2008)

Background: Consumption effects of weather shocks

Residual Variation in 15 Temperature Bins