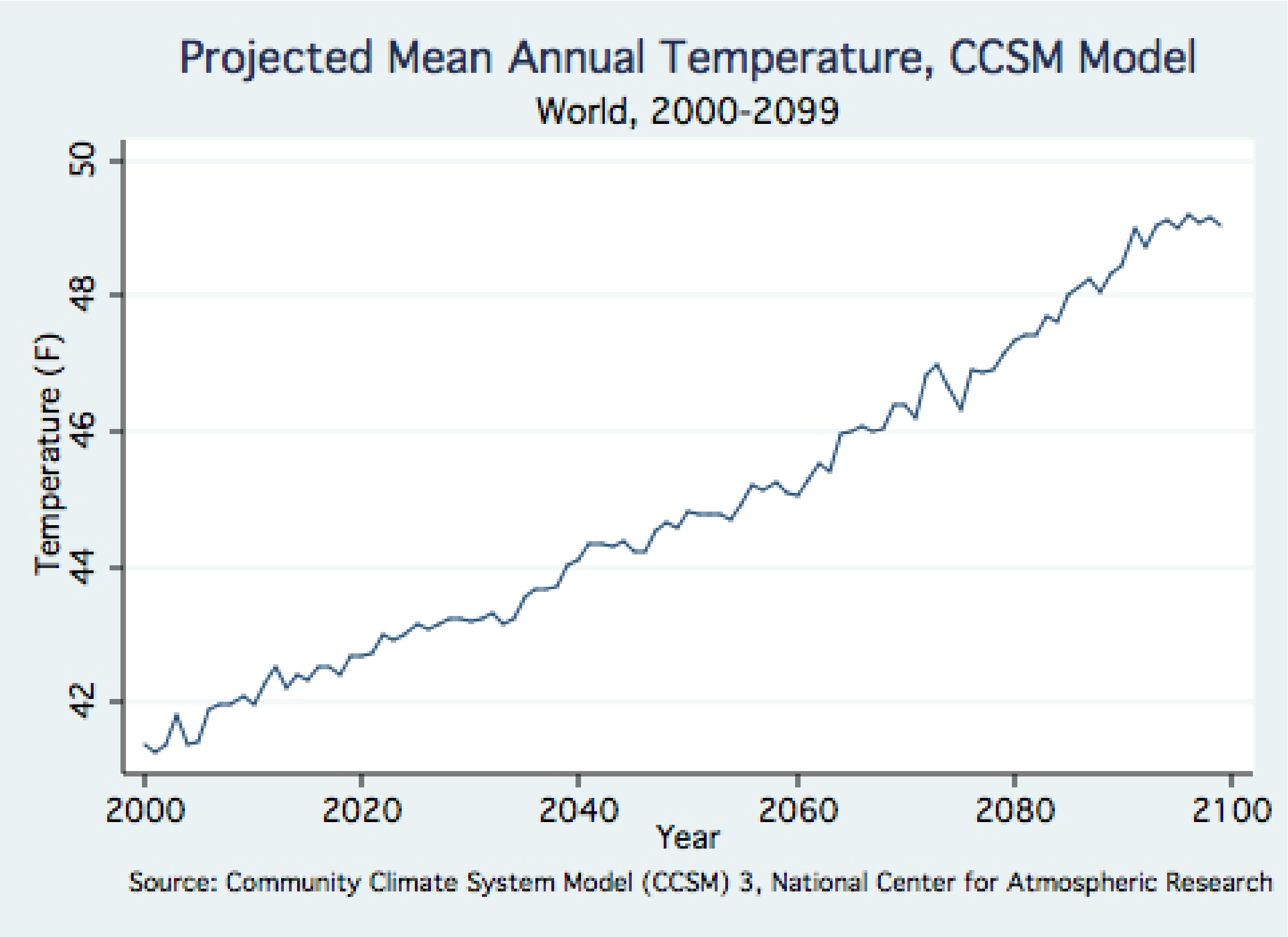
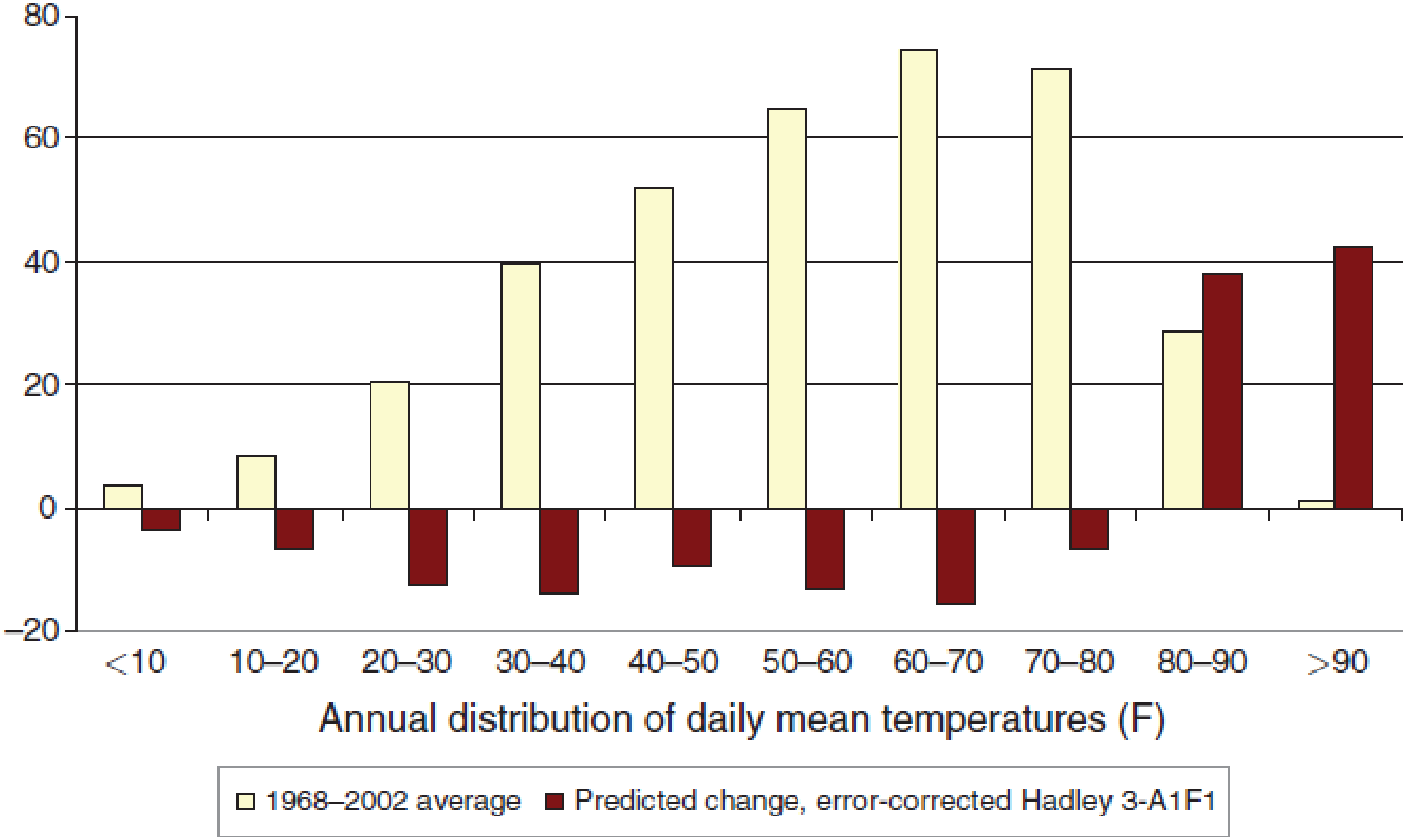
# Introduction: Projected Temperature Increase




Climate scenario: business as usual

# Introduction: Projected U.S. Temperature Increase

Prediction for 2099



## Introduction: Responses to Climate Change

1. Mitigation

    Prognosis: poor

2. Geoengineering

    Prognosis: uncertain

    (Who gets to set the planet's temperature?)

3. Adaptation

    Prognosis: the only certain component of medium-run climate change policy

# Introduction: Adaptation

- "[A]djustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities" --IPCC
  - Policy literature strongly emphasizes adaptation for health

- No credible empirical evidence on human ability to adapt to large-scale environmental change

-interaction of weather and climate
- theory:
  - Hsaing and Tatiana Deryugina (marginal product of climate), Lemoine, Kolstad, Grossman
- data on technologies / and behaviors

# Introduction: Research Questions

1. How did the temperature-mortality relationship change during the 20th century U.S.?

2. How did health-related innovations change the temperature-mortality relationship?

(Which subpopulations gained the most from heat-protective effects of these innovations?)

(Relevance to climate change and developing countries today?)

# Introduction: Approach

- Mortality and weather, 1900-2004

- Three “modifiers” of temperature-mortality relationship: health care access (doctors per capita), electricity, air conditioning

- Focus: interaction terms of weather and modifiers

- Not a full social welfare analysis of any modifier (today)

# Introduction: Results

1. Effect of very hot days on log mortality rate fell 80% after 1960

2. Air conditioning explains most of this effect. Access to health care and residential electricity: limited roles.

Minorities, infants, elderly benefitted the most.

Climate change and developing countries: air conditioning paradox

# Outline

Physiology

Modifiers

Data

Econometrics

Results

- Changing nature of temperature-mortality relationship
- Evidence on modifiers of temperature-mortality relationship

Interpretations and implications

Conclusions

# Physiology

- Thermoregulation
  - Body maintains 98.6°F
- Extreme ambient temperature
  - Cardiovascular & respiratory systems work harder: sweating, shivering
  - Causes mortality and morbidity
  - US Army guideline: “moderate work” for 15 mins/hour when ambient temperature >90°F
- “Long-term” effect of temperature on mortality
  - Difficult to measure due near-term mortality advancement.
  - (Harvesting)
  - Need long exposure window

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# Modifiers

- Three:
  - Access to health care
  - Residential electricity
  - Residential air conditioning
- Many people in developing countries lack these
- Other adaptations possible (e.g, migration)

# Modifiers: Mechanisms

- Access to health care (1900-2004)
  - Hospital interventions including cooling and oral or IV fluids

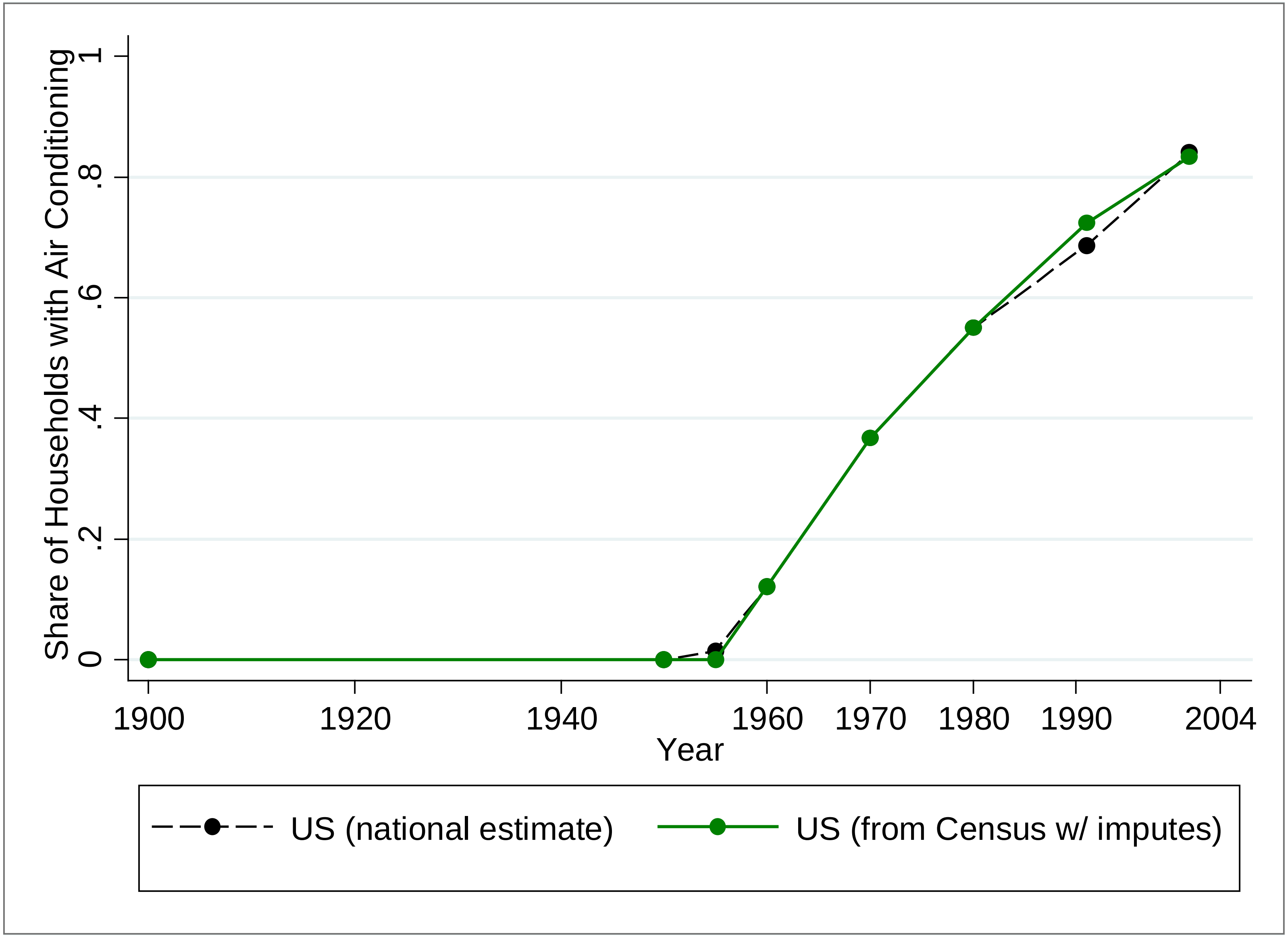
- Electricity (1900-1950s)
  - All households have electricity by 1950s
  - Fans, electric heating, smokeless lighting, refrigeration, piped water

- Residential air conditioning (1955-2004)

# Modifiers: Residential Air Conditioning

- History (Biddle 2008)
- Negligible household access before 1950s
  - Shops had air conditioning beginning in 1920s
- Why residential air conditioning begins in 1950s?
  - Change in standard methods of residential construction
  - Regulatory change: central AC included in FHA-approved mortgages

# Modifiers: Residential Air Conditioning Coverage



# Modifiers: Summary Statistics

| | Number of Doctors Per 1000 Population | | | Share of Households With With Electricity | | | Share of Households With Residential Air Conditionning | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **1920** | **1960** | **2004** | **1920** | **1960** | **2004** | **1920** | **1960** | **1980** | **2004** |
| **A. All States:** | 1.28 | 1.33 | 2.90 | 0.52 | 1.00 | 1.00 | 0.00 | 0.12 | 0.55 | 0.87 |
| **B. By US Census Region:** | | | | | | | | | | |
| 1. Northeast | 1.25 | 1.76 | 3.88 | 0.75 | 1.00 | 1.00 | 0.00 | 0.10 | 0.43 | 0.74 |
| 2. Midwest | 1.27 | 1.18 | 2.67 | 0.58 | 1.00 | 1.00 | 0.00 | 0.11 | 0.54 | 0.93 |
| 3. South | 1.21 | 1.05 | 2.74 | 0.20 | 1.00 | 1.00 | 0.00 | 0.18 | 0.73 | 1.00 |
| 4. West | 1.62 | 1.52 | 2.59 | 0.71 | 1.00 | 1.00 | 0.00 | 0.07 | 0.38 | 0.72 |

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# Data: Weather

- Global Historical Climatology Network
  - Daily minimum and maximum temperature
  - Precipitation
  - Average 1,800 stations/year, 1900 to 2004
  - To counties: inverse-distance weight (radius: 300 km)
  - To states: population-weighted mean across counties

- Humidity: limited data
  - Temperature*precipitation as proxy
  - Barreca (2012): humidity doesn’t affect temperature-mortality relationship

# Data: Mortality

- Mortality
  - Mortality Statistics of the United States (1900-1958, books)
  - Multiple Cause of Death (1959-2004, computerized)
  - Unbalanced panel in early 1900s
  - Public data >2004 lack geocodes

- Other mortality data candidates
  - Daily: only 1972-1988
  - County: sporadic pre-1959

- State*Year*Month data is best available for 20$^{th}$ century

# Data: Mortality Rates

- Mortality Rates
- 1900-2004: total mortality rate
  - 1960-2004: by cause of death and demography
    - Age: Infants, 1-44, 45-64, 65+
    - Race: white, black
    - Cause: cardiovascular, neoplasms, respiratory, infections, vehicle accident

- Separate results for:
  - Vulnerable populations
  - Causes of death linked to extreme heat

## Data: Modifiers

- Physicians per capita:
  - State-year data from decennial Population Census
  - Linearly interpolate

- Share households with electricity:
  - National Electric Light Association reports (annual)
  - Edison Electric Institute reports (annual)

- Share households with residential air conditioning:
  - State-year data from 1960, 1970, 1980 Population Census
  - Linearly interpolate

# Data: Other

- Annual Income Per Capita
  - Source: BEA
  - 1929+ only

# Outline

# Econometrics: Regression Equation

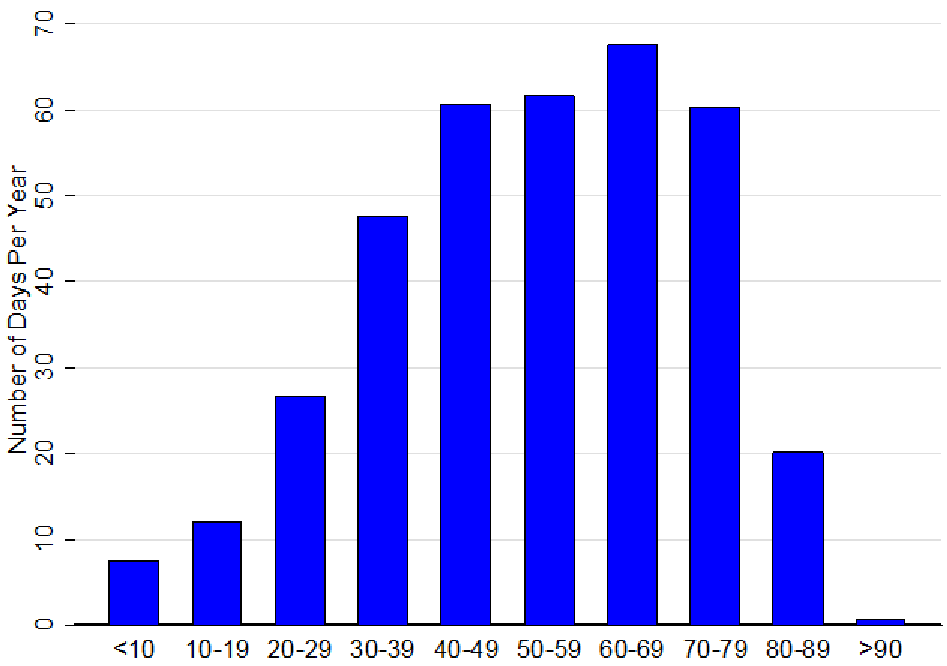
$$\log(Y_{sym}) = \sum_j \theta_j TMEAN_{symj} + \pi_L LOWP_{sym} + \pi_H HIGHP_{sym} +$$
$$X_{sym}\beta + \alpha_{sm} + \gamma_{ym} + \varepsilon_{sym}$$

- *sym*: unit of observation is a state×year×month

# Econometrics: Regression Equation

$$\log(Y_{sym}) = \sum_j \theta_j TMEAN_{symj} + \pi_L LOWP_{sym} + \pi_H HIGHP_{sym} +$$
$$X_{sym}\beta + \alpha_{sm} + \gamma_{ym} + \varepsilon_{sym}$$

- *sym*: unit of observation is a state×year×month
- *j*: temperature bins



# Econometrics: Regression Equation

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- *sym*: unit of observation is a state×year×month
- *j*: temperature bins

- Fixed Effects and Trends:
  - Year-month (aggregate health trends)
  - State-month (local health seasonality)
  - State-month quadratic trends (local trends in health seasonality)

# Econometrics: Regression Equation

$$\log(Y_{sym}) = \sum_j \theta_j TMEAN_{symj} + \pi_L LOWP_{sym} + \pi_H HIGHP_{sym} + X_{sym}\beta + \alpha_{sm} + \gamma_{ym} + \varepsilon_{sym}$$

- *sym*: unit of observation is a state×year×month
- *j*: temperature bins

- Fixed Effects and Trends:
  - Year-month (aggregate health trends)
  - State-month (local health seasonality)
  - State-month trends (local trends in health seasonality)

- Other controls:
  - Log income per-capita
  - Month * Log per capita income
  - Share in urban areas,
  - Share in four age categories: infants (0); 1-44; 45-64; and 65+

# Econometrics: Notes

- Alternative model: 3 temperature bins
  - days<40°F
  - days 80-89°F
  - days>90°F

- Alternative model: 2 months of lagged exposure
  - Cumulative effects
  - To address displacement effects.
  - Sensitivity analysis: 4 month window

- Preferred model: include income controls

## Econometrics: Notes

- Weighted by state-year population
- Clustered by state
- Modifiers: main effects and interactions with temperature

# Econometrics: Identification

- Non-experimental variation in modifiers
- Fixed effects and trends help identification
- Internal validity threats:
  - State*year*month variables correlated with air conditioning adoption and temperature-mortality relationship
- One check: include temperature*year trends as additional control.
- Another check: estimate ‘leads’ of temperature
- Effects found are for extreme temperatures, not for a secular increase in temperature tolerance

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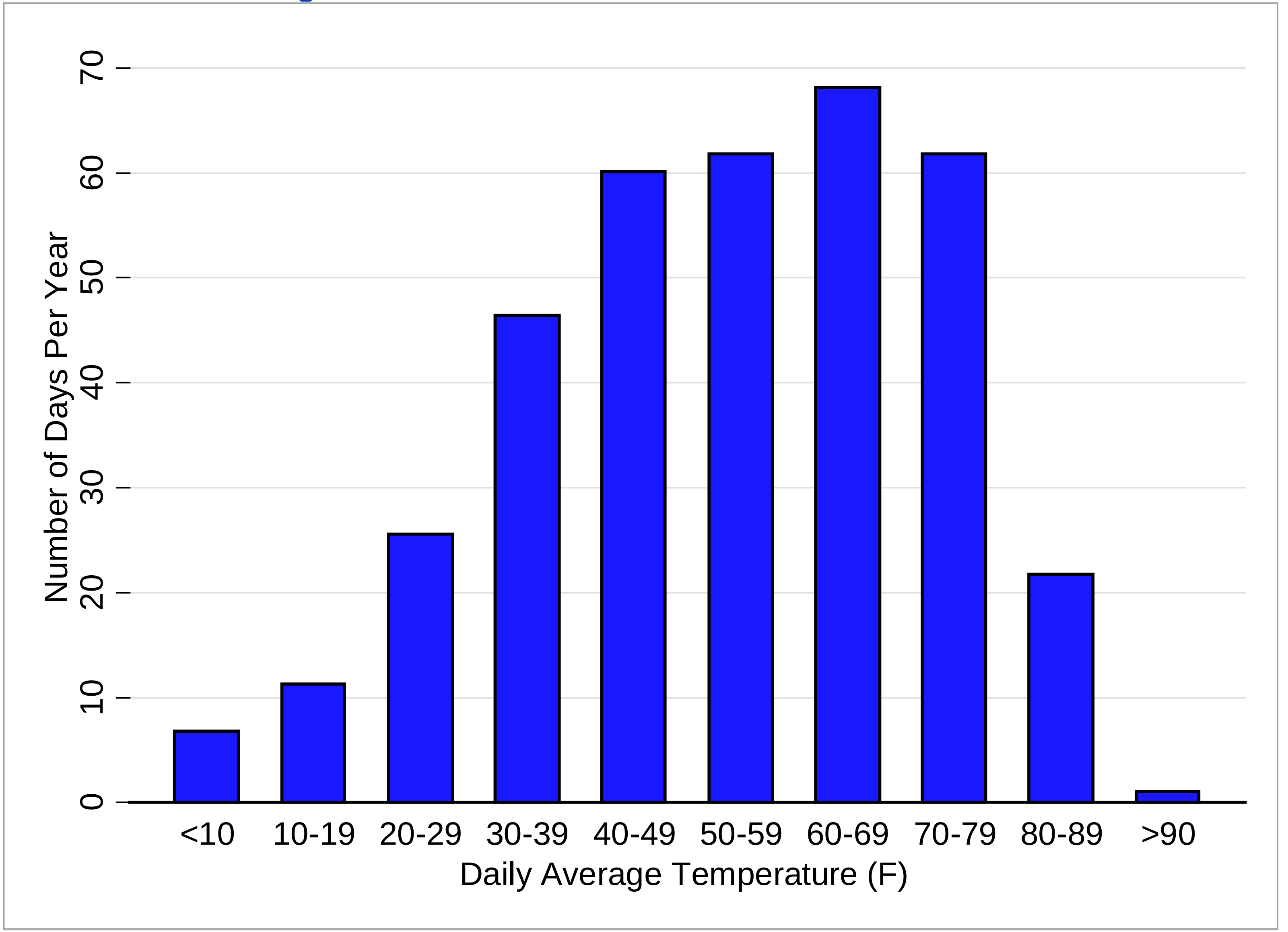
# Daily Mean US Temperatures

weighted by population
distribution over course of one year
1900-2004 average



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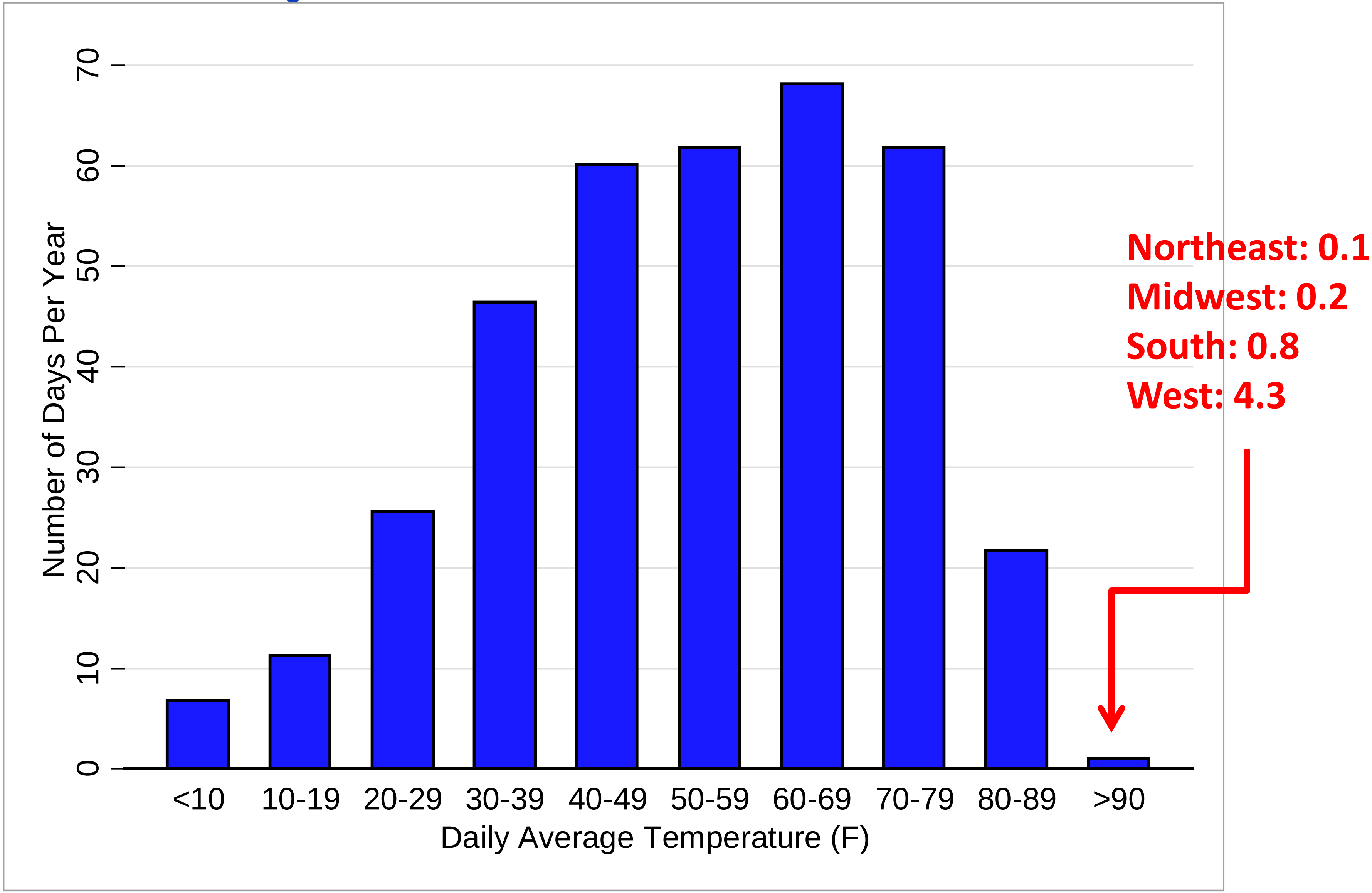
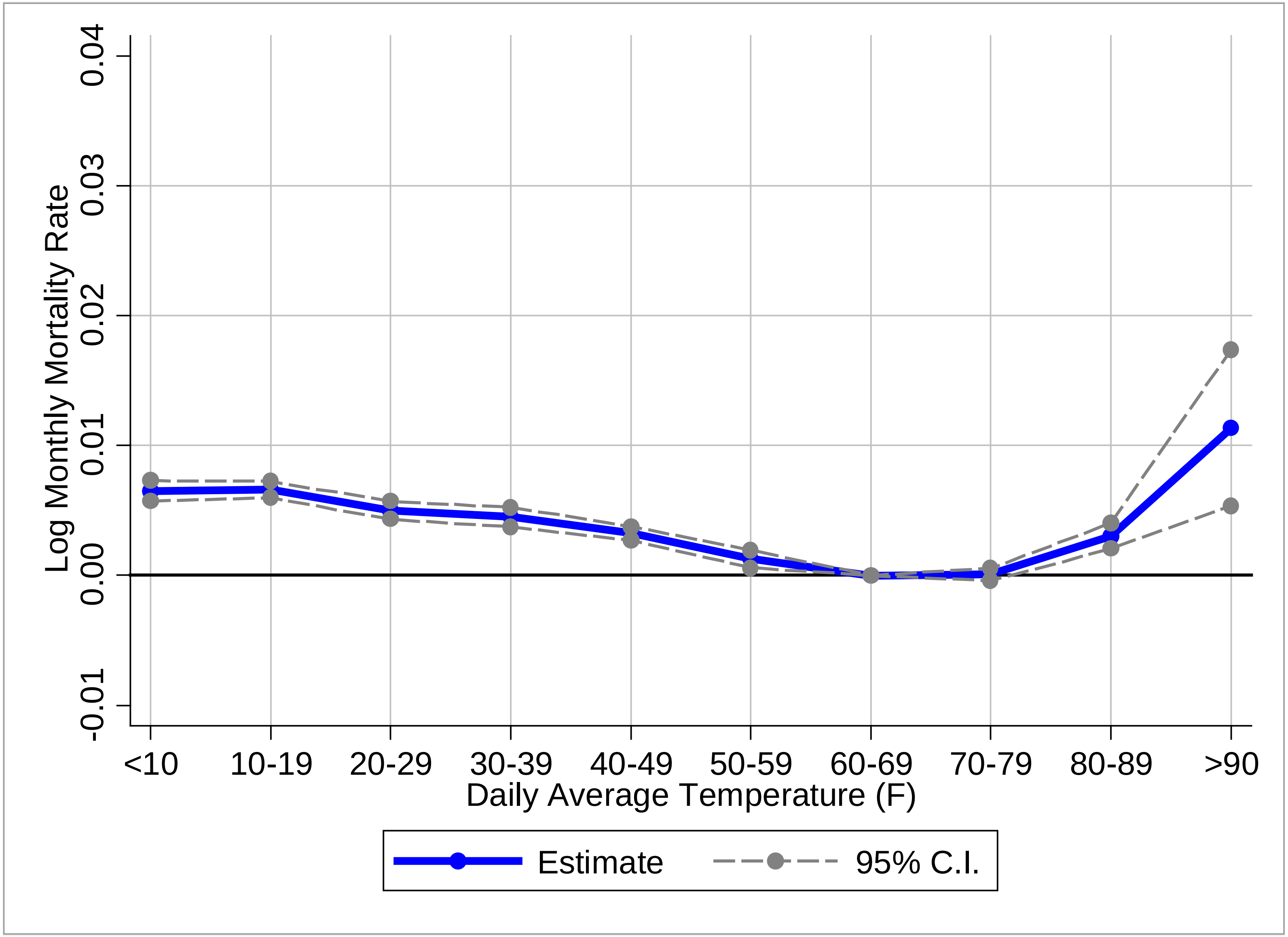


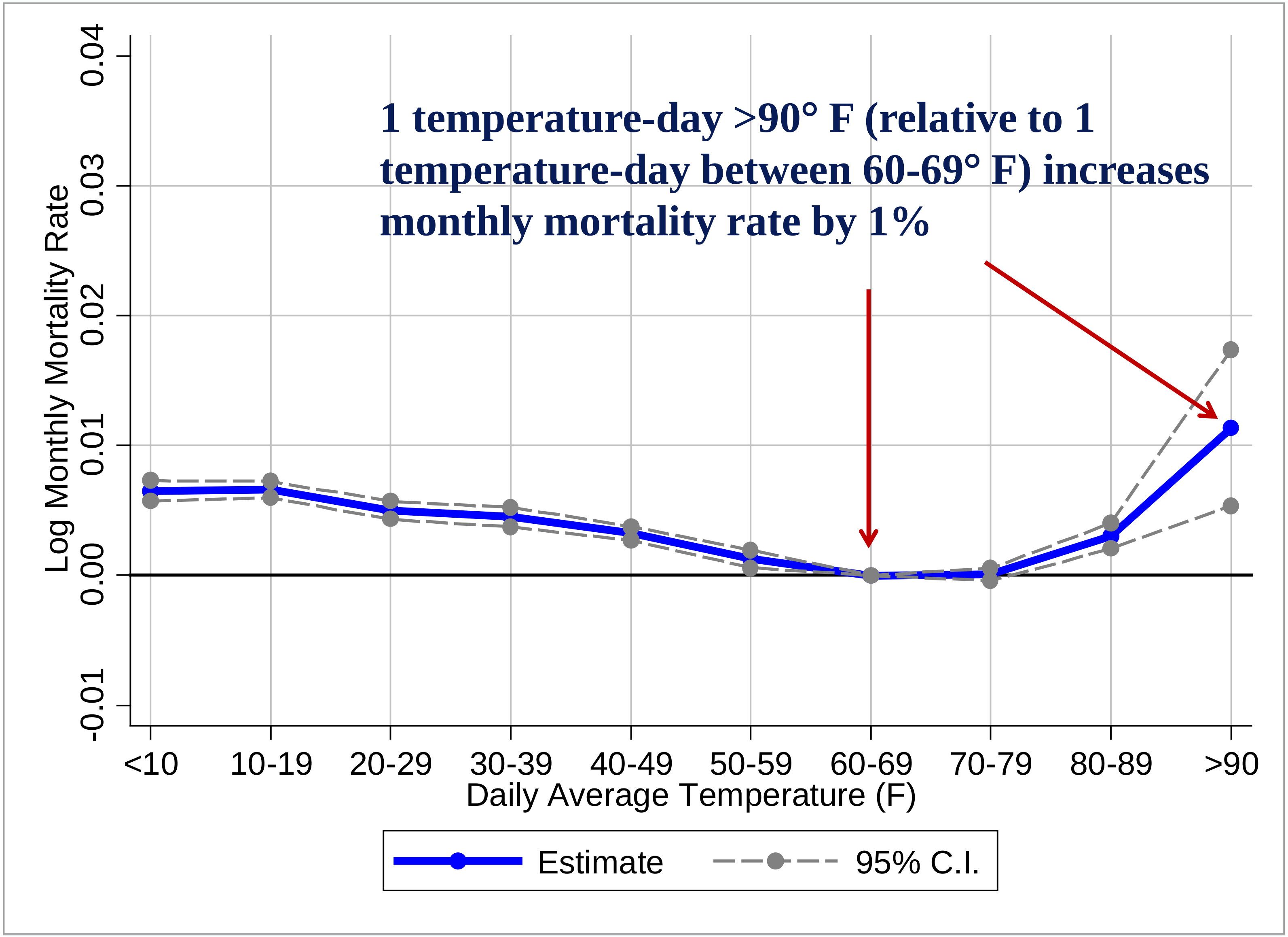
# Temperature and Log Monthly Mortality Rates

1900-2004



# Temperature and Log Monthly Mortality Rates

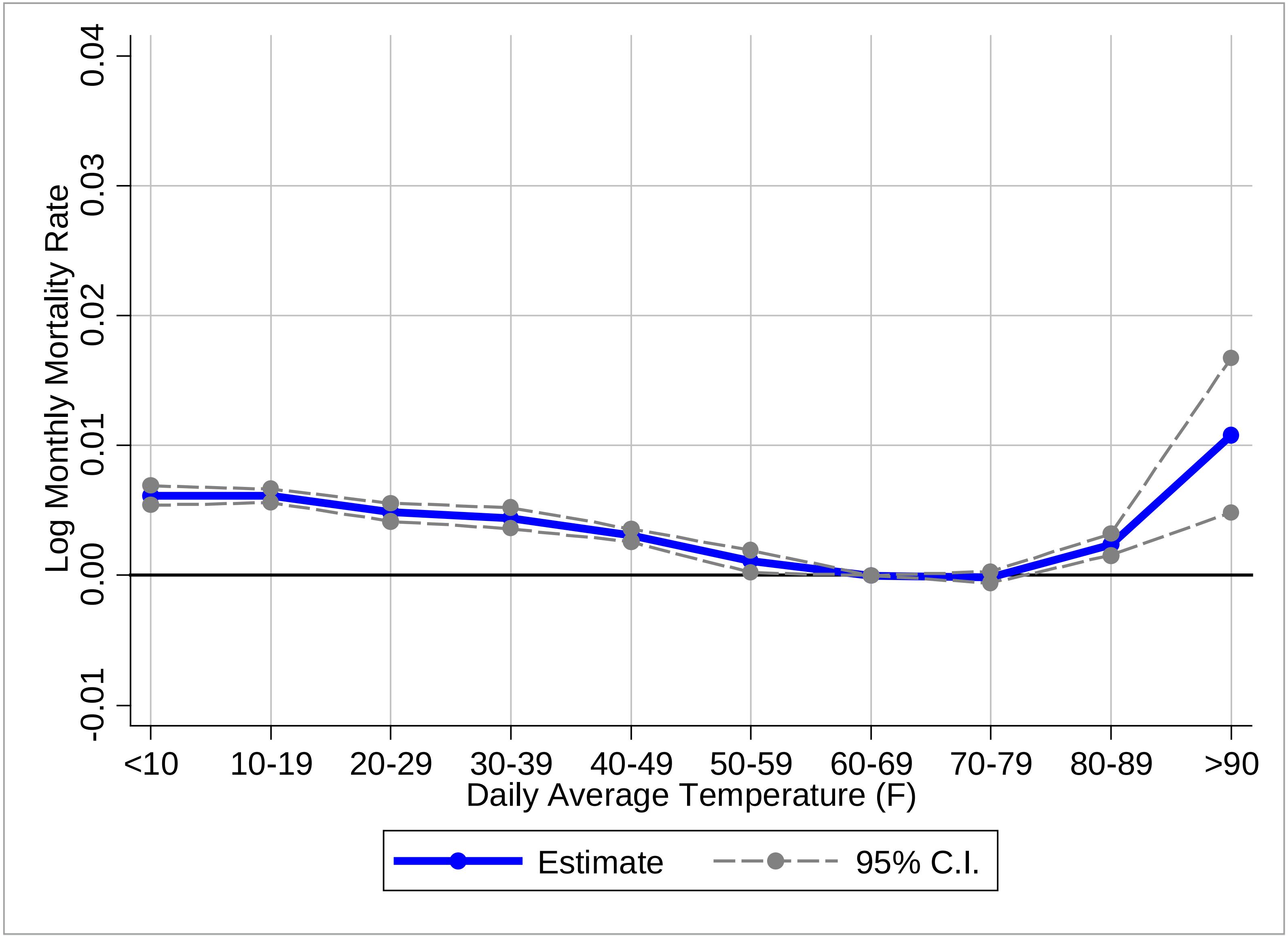
1900-2004



# Temperature and Log Monthly Mortality Rates

1929-2004

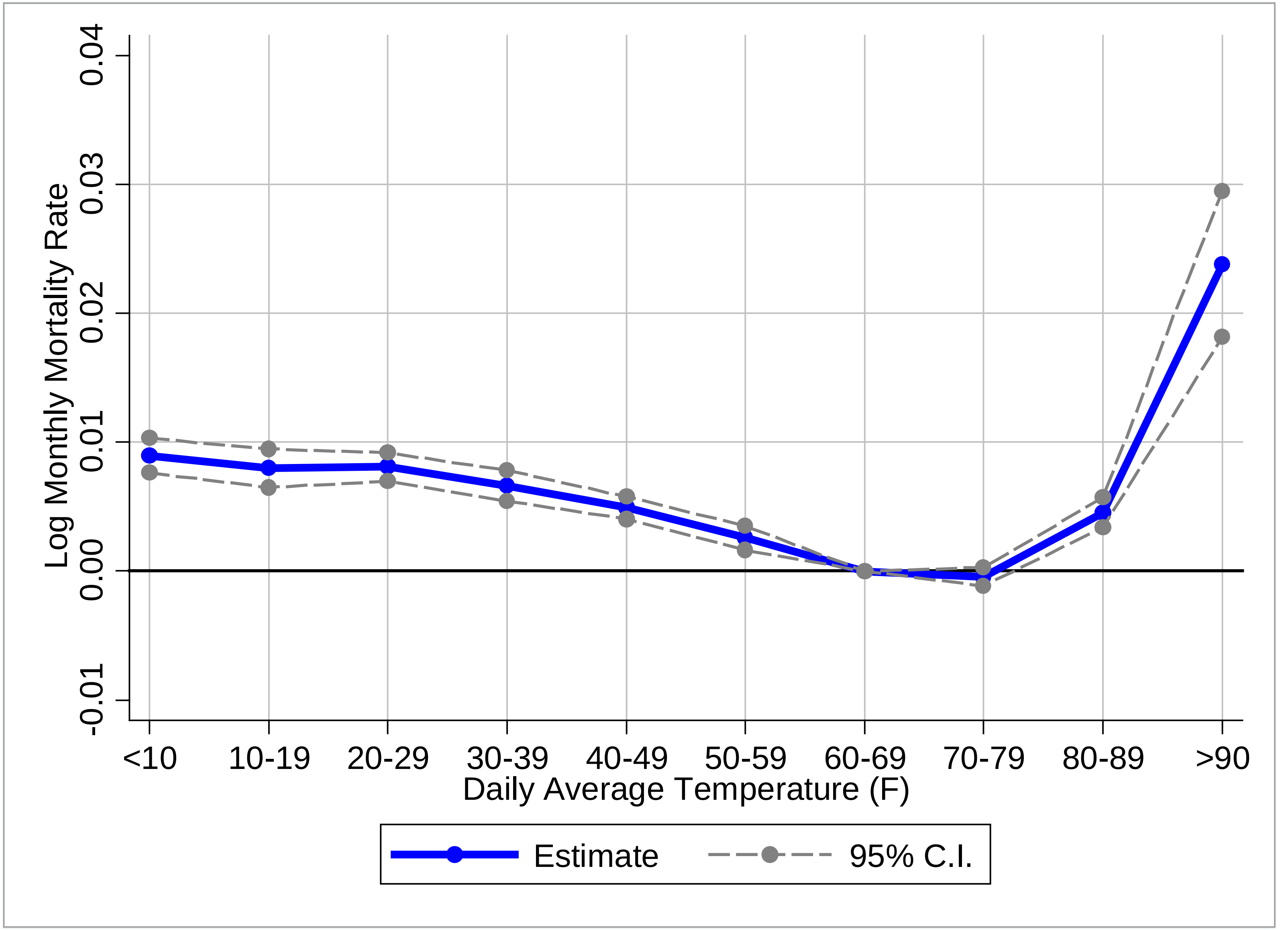
Control for log per capita income



# Temperature and Log Monthly Mortality Rates

1929-1959

~1600 deaths per year due to >90° F



# Temperature and Log Monthly Mortality Rates

1929-1959

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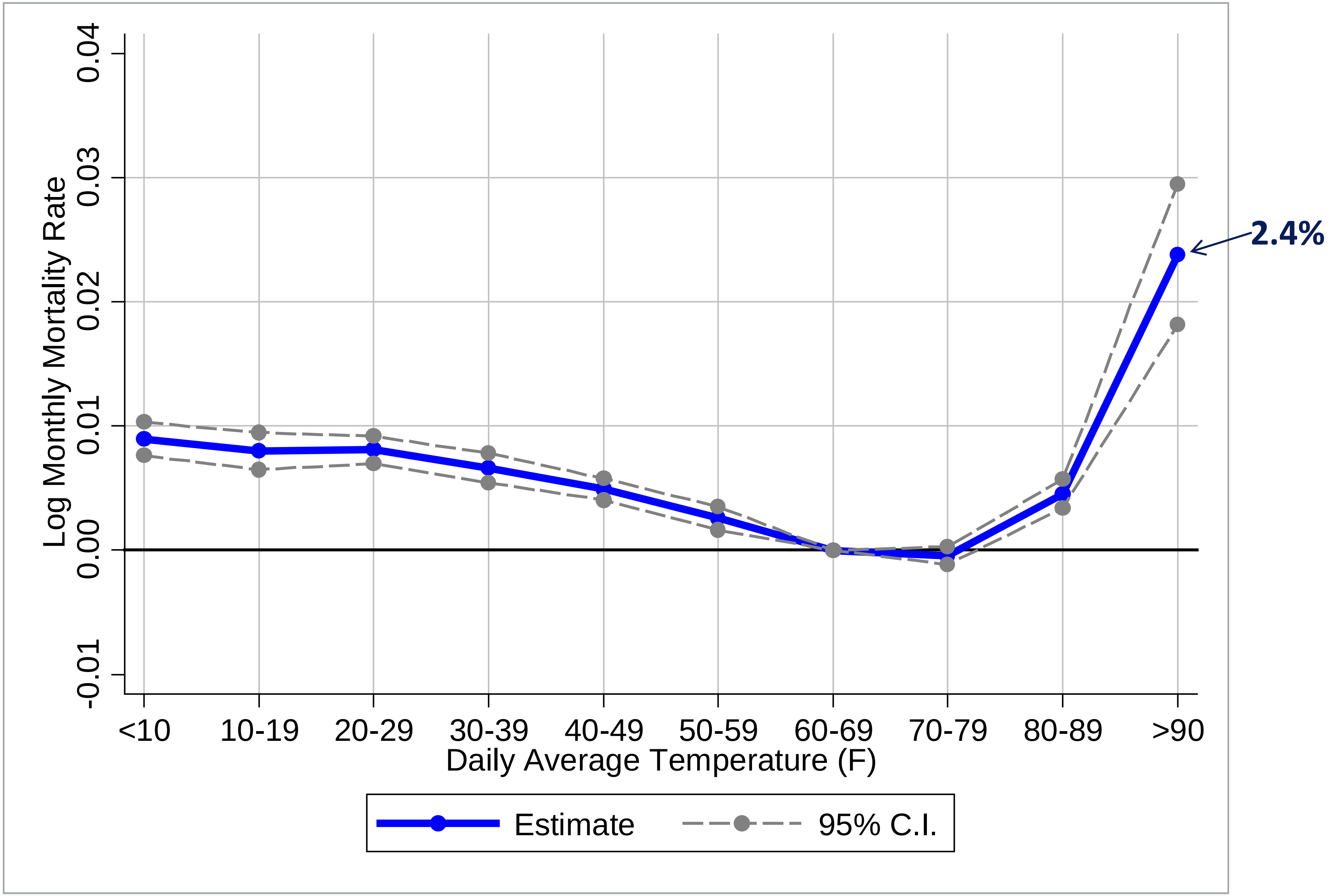
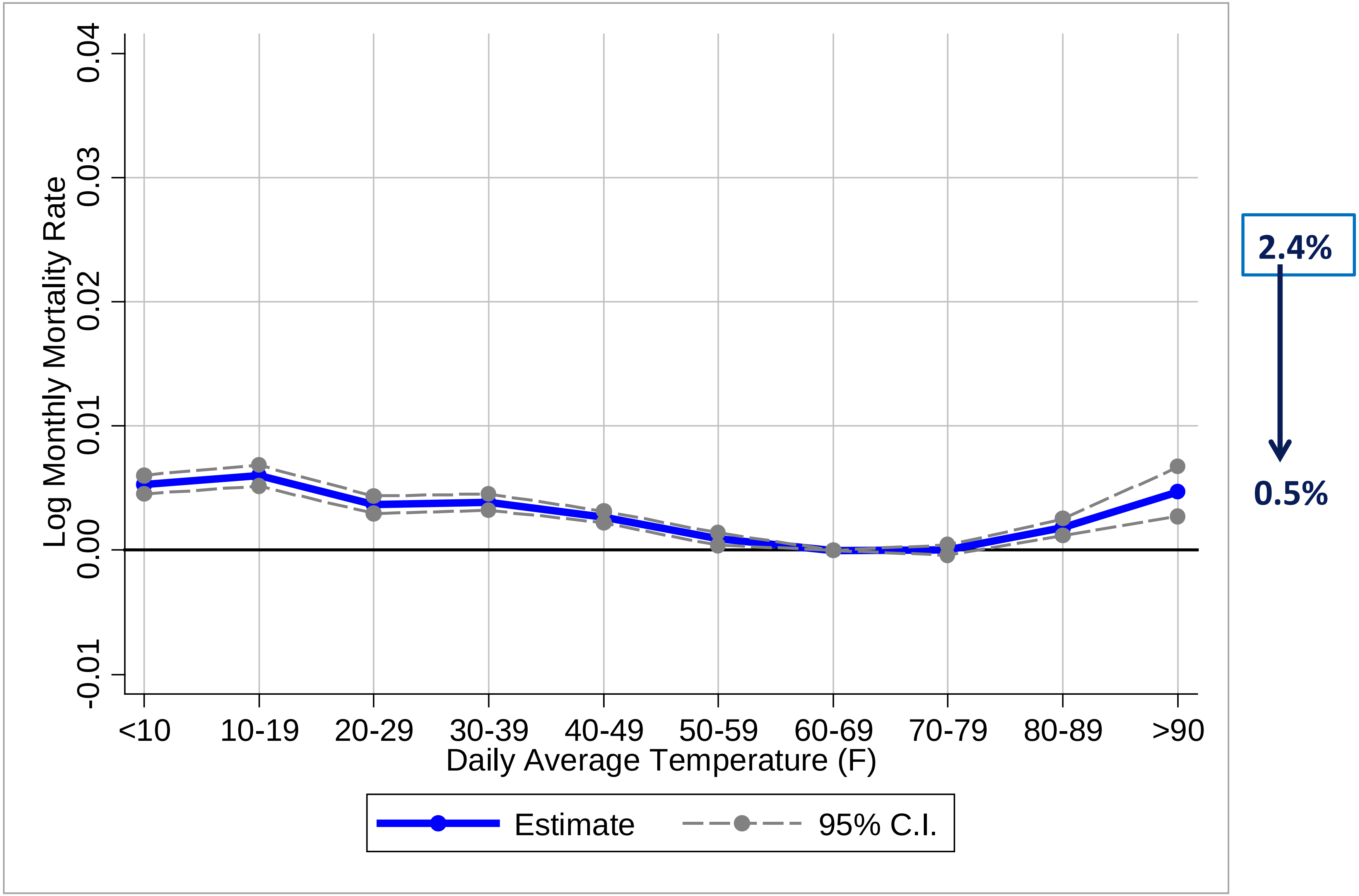


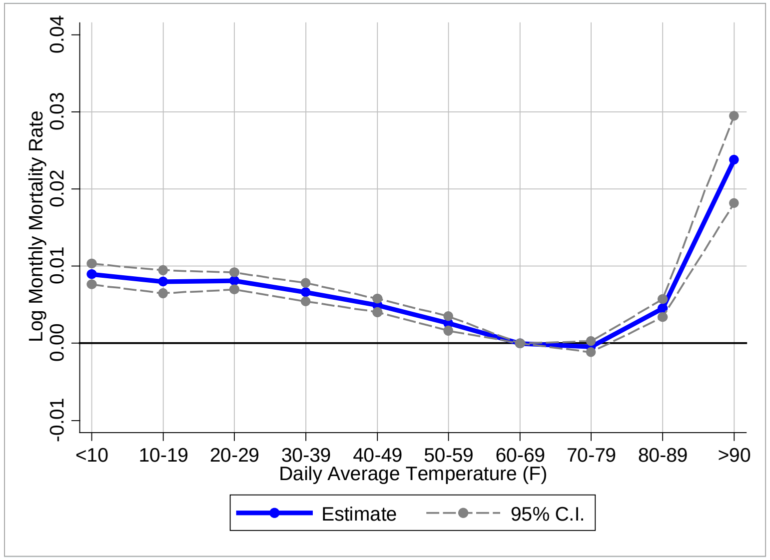
# Temperature and Log Monthly Mortality Rates

1960-2004

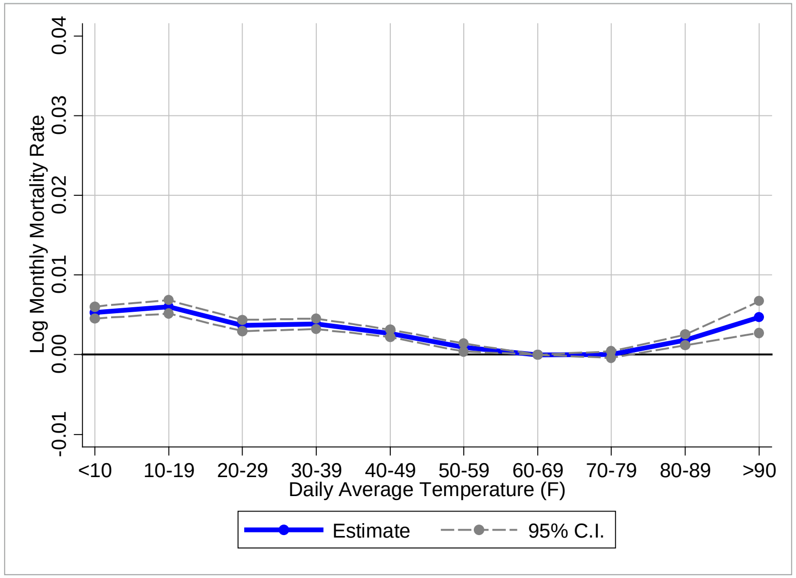
~ 600 deaths per year due to >90° F



# Temperature and Log Monthly Mortality Rates



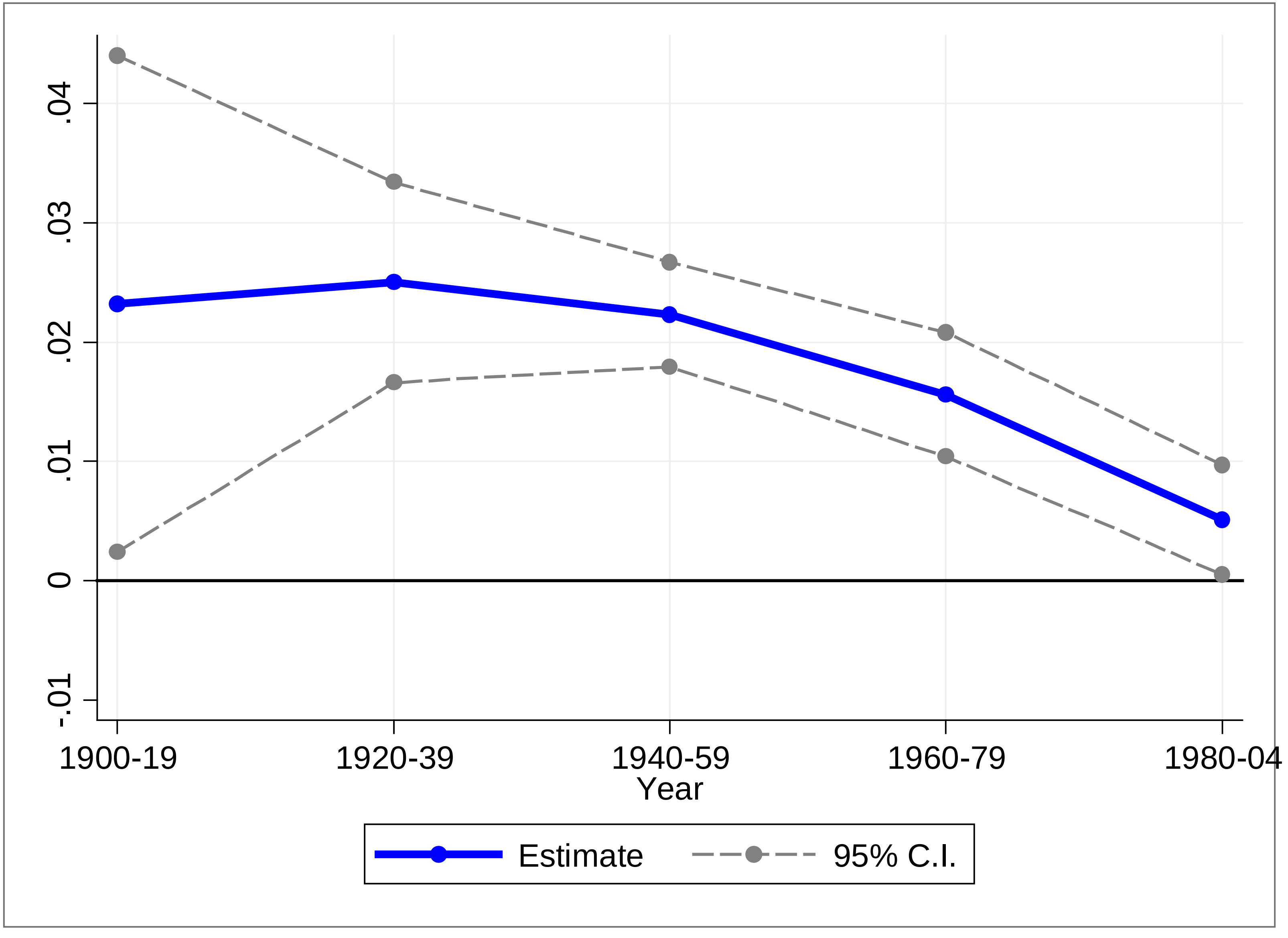

1929-1959




1960-2004

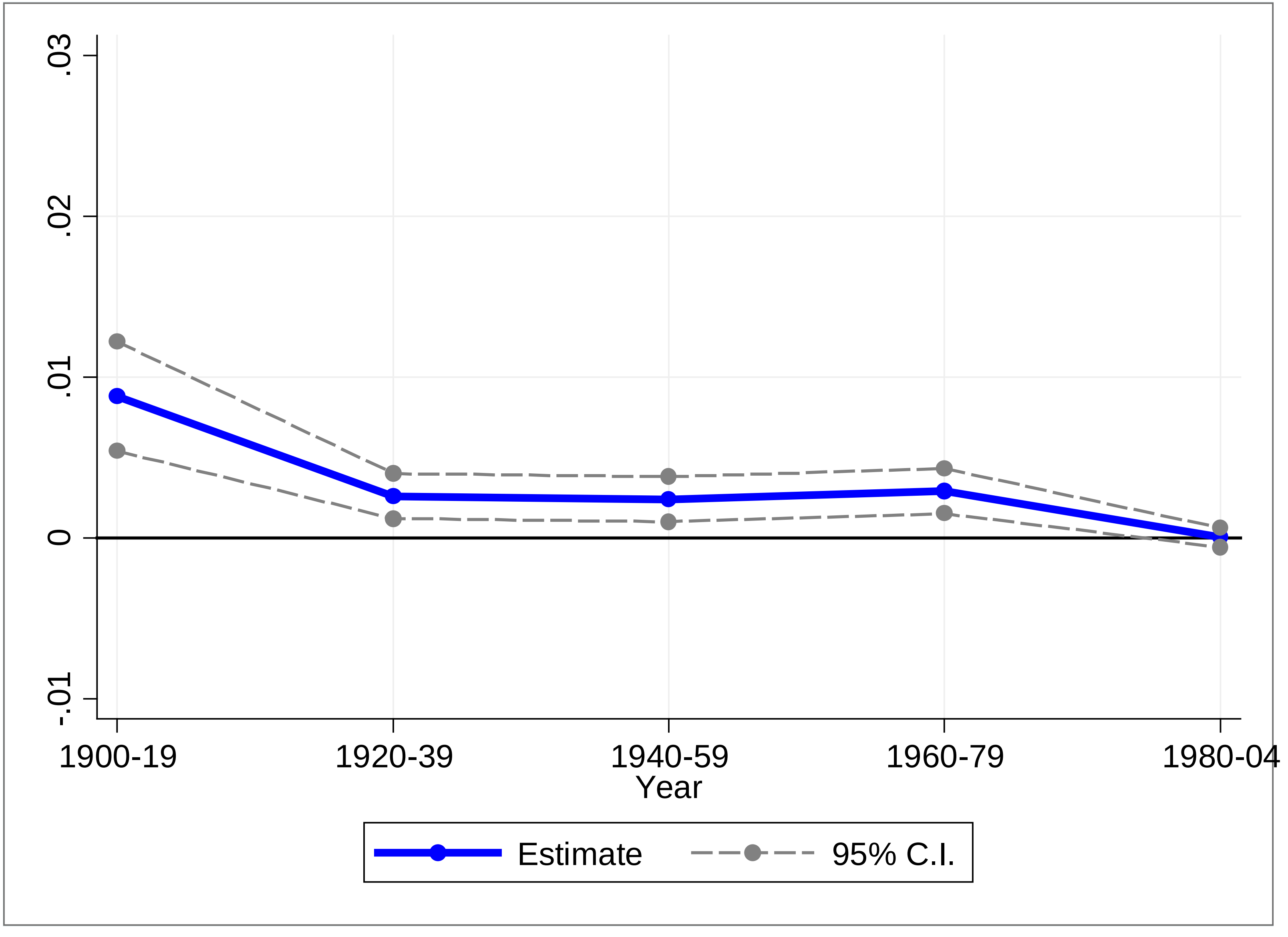
# Days > 90°F and Log Monthly Mortality Rates

By 20 year period



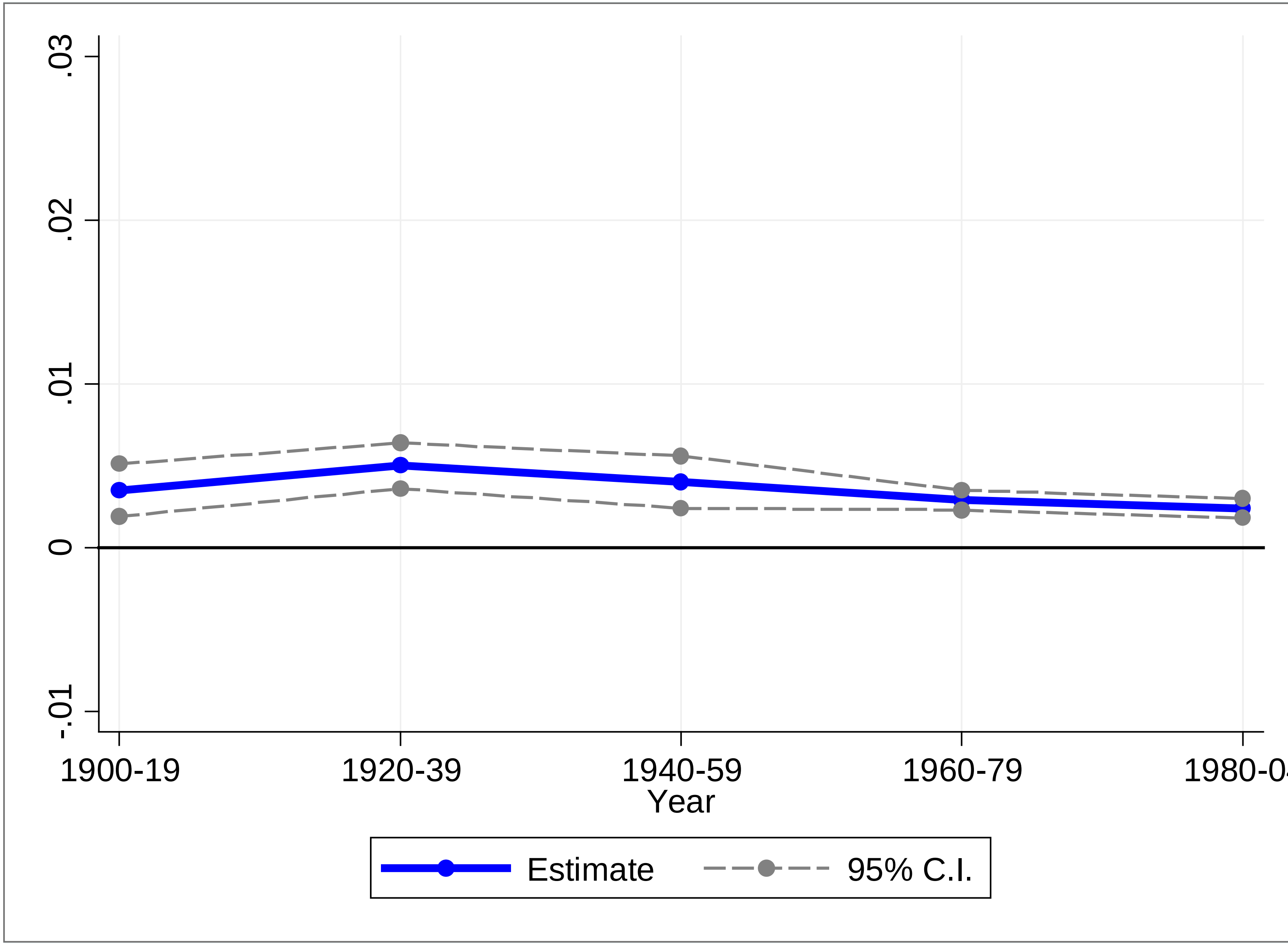
# Days 80-89°F and Log Monthly Mortality Rates

By 20 year period



# Days <40°F and Log Monthly Mortality Rates

By 20 year period



# Temperature and Log Monthly Mortality

## Contemporaneous effect (1 month exposure)

| | Sample: | | | |
|---|---|---|---|---|
| | 1900-2004 | 1929-2004 | 1929-1959 | 1960-2004 |
| | (1) | (2) | (3) | (4) |
| **A. 1 Month Exposure Window** | | | | |
| Number of Days Above 90°F | 0.0114* | 0.0110* | 0.0243* | 0.0047* |
| | (0.0030) | (0.0029) | (0.0028) | (0.0010) |
| Number of Days Between 80-89°F | 0.0030* | 0.0024* | 0.0048* | 0.0018* |
| | (0.0004) | (0.0003) | (0.0004) | (0.0002) |
| Number of Days Below 40°F | 0.0029* | 0.0029* | 0.0039* | 0.0024* |
| | (0.0003) | (0.0003) | (0.0007) | (0.0002) |
| Year*Month Fixed Effects | y | y | y | y |
| State*Month Fixed Effects | y | y | y | y |
| State*Month Quad Time Trends | y | y | y | y |
| Month*Income Interactions | n | y | y | y |

~ 5-fold reduction, pre/post 1960

Notes: Regressions also include log per-capita income (cols 2-4), the share of the population living in urban areas, and the share of the state population in one of four age categories: infants (0-1); 1-44; 45-64; and 65+. Regressions are weighted by state population and standard errors are clustered at the state level.

# Temperature and Log Monthly Mortality

## Cumulative effect (2 months exposure)

| | Sample: | | | |
|---|---|---|---|---|
| | 1900-2004 | 1929-2004 | 1929-1959 | 1960-2004 |
| | (1) | (2) | (3) | (4) |
| **B. 2 Months Exposure Window (Cumulative Effect)** | | | | |
| Number of Days Above 90°F | 0.0089* | 0.0086* | 0.0195* | 0.0033* |
| | (0.0026) | (0.0027) | (0.0030) | (0.0009) |
| Number of Days Between 80-89°F | 0.0019* | 0.0012* | 0.0030* | 0.0011* |
| | (0.0004) | (0.0003) | (0.0005) | (0.0002) |
| Number of Days Below 40°F | 0.0042* | 0.0041* | 0.0059* | 0.0034* |
| | (0.0004) | (0.0004) | (0.0008) | (0.0003) |
| Year*Month Fixed Effects | y | y | y | y |
| State*Month Fixed Effects | y | y | y | y |
| State*Month Quad Time Trends | y | y | y | y |
| Month*Income Interactions | n | y | y | y |

**~ 6-fold reduction, pre/post 1960**

Notes: Regressions also include log per-capita income (cols 2-4), the share of the population living in urban areas, and the share of the state population in one of four age categories: infants (0-1); 1-44; 45-64; and 65+. Regressions are weighted by state population and standard errors are clustered at the state level.

# Temperature and Log Monthly Mortality

## Separate effects for minimum and maximum temperatures

| | Sample: | | |
|---|---|---|---|
| | 1929-2004 | 1929-1959 | 1960-2004 |
| | (1) | (2) | (3) |
| **A. Daily Minimum Temperature** | | | |
| Number of Days Above 80°F | 0.0035 | 0.0208* | 0.0010 |
| | (0.0018) | (0.0069) | (0.0008) |
| Number of Days Between 70-79°F | 0.0005 | 0.0027* | 0.0007 |
| | (0.0007) | (0.0007) | (0.0006) |
| **B. Daily Maximum Temperature** | | | |
| Number of Days Above 100°F | 0.0034* | 0.0045* | 0.0014* |
| | (0.0008) | (0.0014) | (0.0006) |
| Number of Days Between 90-99°F | 0.0007 | 0.0000 | 0.0005 |
| | (0.0008) | (0.0006) | (0.0003) |
| Year*Month Fixed Effects | y | y | y |
| State*Month Fixed Effects | y | y | y |
| State*Month Quad Time Trends | y | y | y |
| Month*Income Interactions | y | y | y |

**~ 21-fold reduction, pre/post 1960**

Notes: Regressions also include log per-capita income, the share of the population living in urban areas, and the share of the state population in one of four age categories: infants (0-1); 1-44; 45-64; and 65+. Regressions are weighted by state population and standard errors are clustered at the state level.

# Heterogeneity & Robustness

- Differences by US region:
  - Magnitude of effect inversely related to local climates
  - No statistically significant differences
  - Similar ‘flattening’ of temperature-mortality relationship

# Temperature and Log Monthly Mortality

## By US Census Region, cumulative effect (2 months exposure)

| | Number of Days Below 40° F | | Number of Days Between 80-89F° | | Number of Days Above 90° F | |
|---|---|---|---|---|---|---|
| | 1929-1959 | 1960-2004 | 1929-1959 | 1960-2004 | 1929-1959 | 1960-2004 |
| | (1a) | (1b) | (2a) | (2b) | (3a) | (3b) |
| 1. Northeast | 0.0054* | 0.0025* | 0.0032* | 0.0031* | -0.0133 | 0.0284 |
| | (0.0010) | (0.0004) | (0.0008) | (0.0007) | (0.0217) | (0.0194) |
| 2. Midwest | 0.0038* | 0.0019* | 0.0030* | 0.0029* | 0.0280* | 0.0056 |
| | (0.0010) | (0.0002) | (0.0006) | (0.0005) | (0.0036) | (0.0032) |
| 3. South | 0.0102* | 0.0047* | 0.0024* | 0.0006* | 0.0128* | 0.0029 |
| | (0.0014) | (0.0007) | (0.0005) | (0.0002) | (0.0014) | (0.0017) |
| 4. West | 0.0024 | 0.0045* | 0.0046 | 0.0013 | 0.0119* | 0.0033* |
| | (0.0021) | (0.0010) | (0.0028) | (0.0017) | (0.0058) | (0.0014) |

Notes: Regressions also include log per-capita income, the share of the population living in urban areas, and the share of the state population in one of four age categories: infants (0-1); 1-44; 45-64; and 65+. Regressions are weighted by state population and standard errors are clustered at the state level.

# Robustness

## pre/post 1960 mortality effect of high-temperature days

- Robust to:
  - State*year fixed effects
  - Longer exposure window (4 months, not 2)
  - Controlling for fraction black, farm share, urban share
  - Temperature*year trends
  - Temperature*rainfall interactions
  - “Lead” temperature variables (lead variables not significant)

# Robustness Analysis (Table 6)

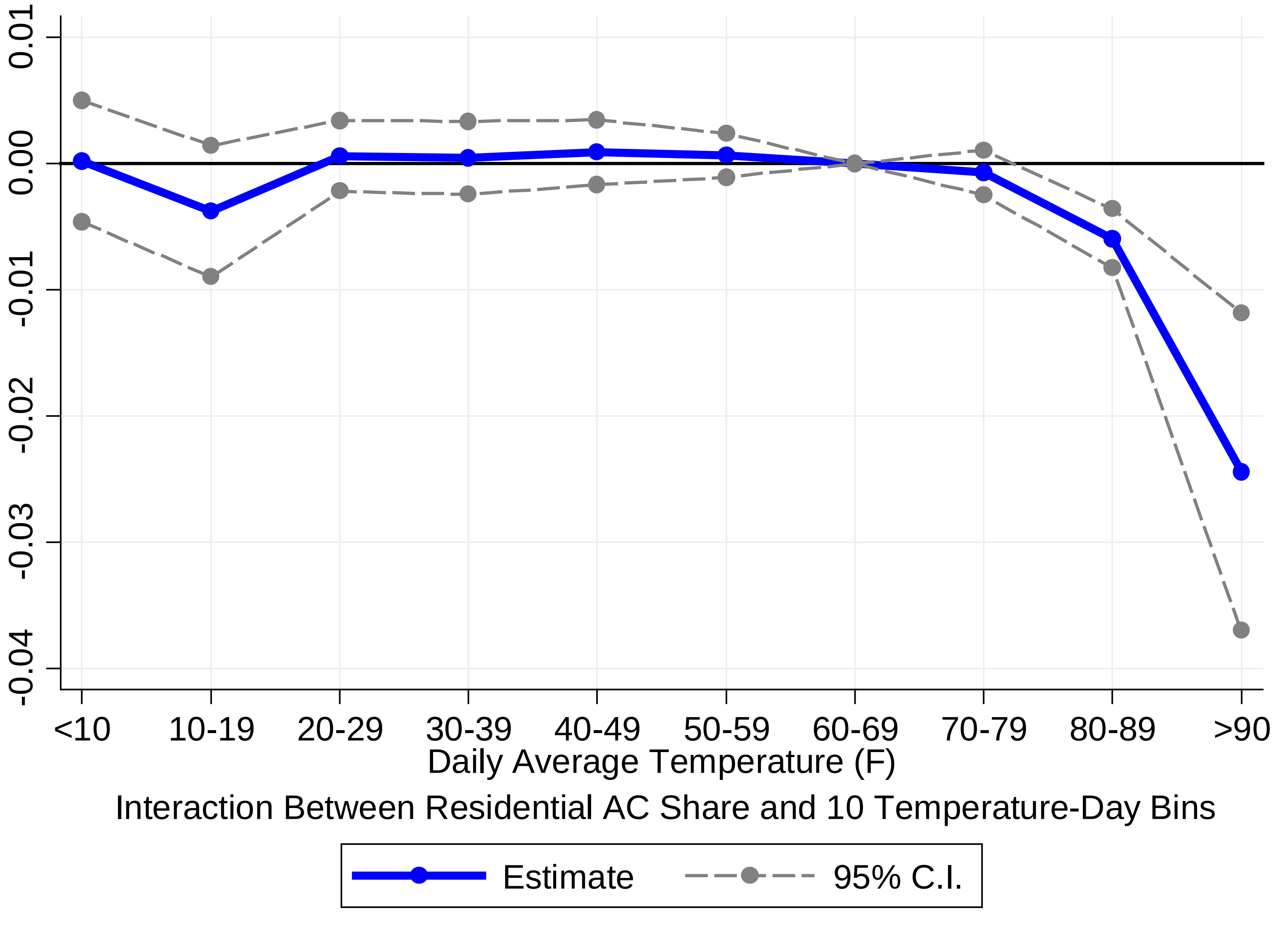
| | Sample: | |
|---|---|---|
| | **1929-1959** | **1960-2004** |
| | (1) | (2) |
| 1. Baseline (Table 3, Panel B) | 0.0195* | 0.0033* |
| | (0.0030) | (0.0009) |
| 2. Controls for State*Year Fixed Effects | 0.0185* | 0.0041* |
| | (0.0035) | (0.0011) |
| 3. Exposure Window of 4 Months | 0.0200* | 0.0007 |
| | (0.0035) | (0.0015) |
| 4. Log Real Per Capita Income Below Median | 0.0187* | 0.0059* |
| | (0.0035) | (0.0018) |
| 5. Log Real Per Capita Income Above Median | 0.0175* | 0.0025* |
| | (0.0062) | (0.0006) |
| 6. Including Fraction Black, Fraction Living on Far | 0.0197* | 0.0033* |
| Fraction Movers as Additional Controls | (0.0029) | (0.0009) |
| 7. Allowing for Temperature*Year Trends | 0.0188* | 0.0039* |
| | (0.0028) | (0.0010) |
| 8. Including Temperature*Rainfall Interactions | 0.0180* | 0.0040* |
| | (0.0033) | (0.0010) |
| 9. Including Leads of Temperature Variables | 0.0193* | 0.0035* |
| | (0.0031) | (0.0009) |
| 10. Impact of 3 Consecutive Days > 90°F | 0.1353* | 0.0181* |
| | (0.0224) | (0.0052) |

# Summary

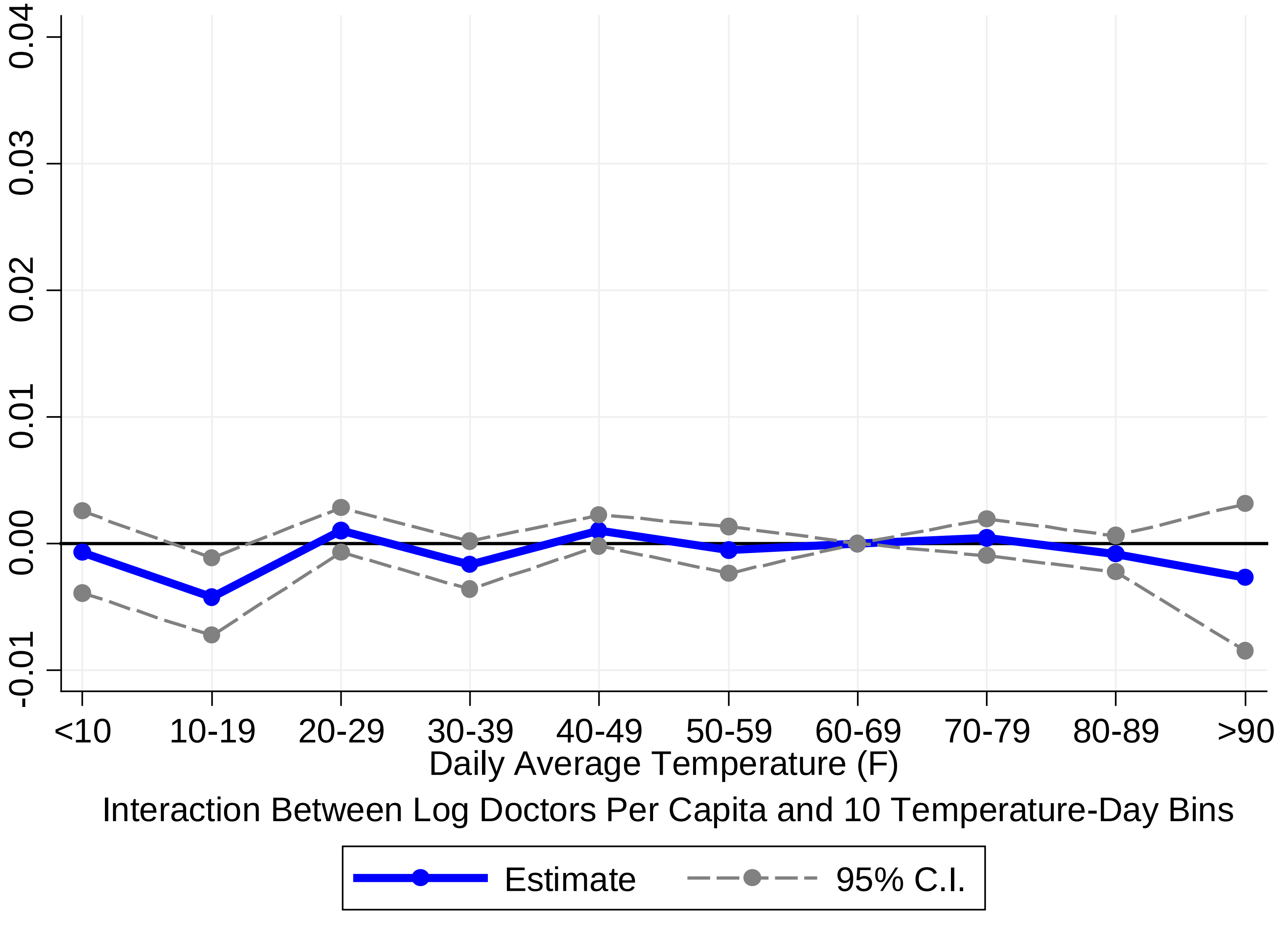
- Impact of very hot days (>90°F) on log mortality rate declined by factor of 5-6 after 1960.
- Similar result in many specifications

# Outline

## Temperature × Residential AC Share
## Effect on Log Monthly Mortality Rate
1960-2004

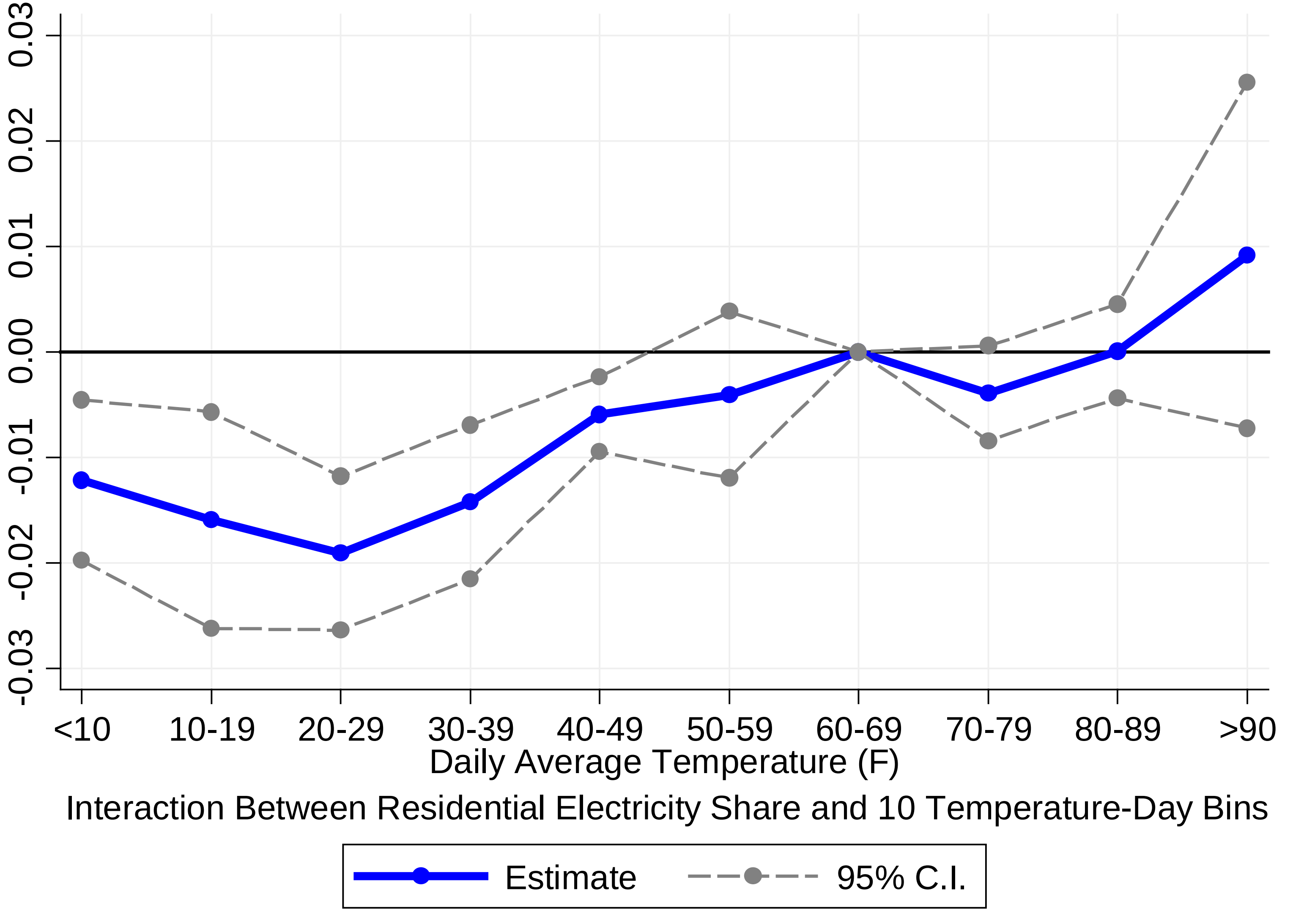


# Temperature × Log Doctors Per Capita
# Effect on Log Monthly Mortality Rate
1960-2004



## Temperature × Residential Electricity Share Effect on Log Monthly Mortality Rate

1929-1959



# Modifiers

## Days>90°F for 1900-1959 and 1960-2004 Sample

| | [A] Sample: 1929-1959 | | | [B] Sample: 1960-2004 | | |
|---|---|---|---|---|---|---|
| | (1a) | (2a) | (3a) | (1b) | (2b) | (3b) |
| Number of Days Above 90°F | 0.0195* | 0.0194* | 0.0194* | 0.0037* | 0.0099* | 0.0096* |
| | (0.0027) | (0.0031) | (0.0029) | (0.0006) | (0.0023) | (0.0025) |
| *Number of Days Above 90 °F ×* | -0.0024 | --- | -0.0019 | -0.0044 | --- | -0.0013 |
| *Log Doctors Per Capita* | (0.0066) | | (0.0074) | (0.0038) | | (0.0025) |
| *Number of Days Above 90 °F ×* | --- | 0.0138 | 0.0138 | --- | --- | --- |
| *Share with Residential Electricity* | | (0.0085) | (0.0102) | | | |
| *Number of Days Above 90 °F ×* | --- | --- | --- | --- | -0.0237* | -0.0226* |
| *Share with Residential AC* | | | | | (0.0063) | (0.0072) |
| Year*Month Fixed Effects | y | y | y | y | y | y |
| State*Month Fixed Effects | y | y | y | y | y | y |
| State*Month Quad Time Trends | y | y | y | y | y | y |
| Month*Income Time Trends | y | y | y | y | y | y |

Notes: Regressions also include log per-capita income, the share of the population living in urban areas, and the share of the state population in one of four age categories: infants (0-1); 1-44; 45-64; and 65+. Regressions are weighted by state population and standard errors are clustered at the state level.

# Robustness of AC Result

- Baseline (Interaction with >90F):

  -0.0226 effect (std error = 0.0072)

- With Temperature*year trends:

  -0.0287 effect (std error = 0.0082)

- With 4 months displacement window:

  -0.0416 effect (std error = 0.0133)

- Interaction with >80F: -0.005 effect (significant)
- Interaction with <40F: not significant

# Modifiers: Sub-Populations

1960-2004 Sample

- Age
  - Protective effect of AC largest for young and old

- Race
  - Protective effect of AC largest for blacks (1.5 times larger than for whites).
  - Significant for both whites and blacks

- Cause of death
  - Protective effect of AC significant for cardiovascular and respiratory disease as expected.
  - Also significant for neoplasms.
  - Insignificant for infectious disease and MVA as expected

# Modifiers: Sub-Populations

1960-2004 Sample

New analysis not in paper

- By income
  - Protective effect of AC same across above/below median income groups
- By min/max temperature
  - Protective effect of AC is largest for high daily minimum (as opposed to high daily maximum). Significant for both
- By “high-risk” industries (as in Graff-Zivin & Neidell):
  - In progress…

# New Analysis

| | [B] Sample: 1960-2004 | | |
|---|---|---|---|
| | (1b) | (2b) | (3b) |
| **1. Daily Mean Temperature** | | | |
| *Number of Days Above 90 °F ×* | --- | -0.0237* | -0.0226* |
| *Share with Residential AC* | | (0.0063) | (0.0072) |
| | | | |
| *Number of Days Above 90 °F ×* | --- | 0.0012 | 0.0041 |
| *Share with Residential AC ×* | | (0.0017) | (0.0032) |
| *Above Median Income* | | | |
| | | | |
| **2. Daily Min/Max Temperature** | | | |
| *Number of Days With Min Above 80 °F ×* | --- | -0.0133 | -0.0173* |
| *Share with Residential AC* | | (0.0086) | (0.0056) |
| | | | |
| *Number of Days With Max Above 100 °F ×* | --- | -0.0100* | -0.0089* |
| *Share with Residential AC* | | (0.0029) | (0.0020) |
| | | | |
| | | | |
| | | | |
| Year*Month Fixed Effects | y | y | y |
| State*Month Fixed Effects | y | y | y |
| State*Month Quad Time Trends | y | y | y |
| Month*Income Time Trends | y | y | y |

# Table 8: By Age

| | (1) | (2) | (3) |
|---|---|---|---|
| **Age 0-1** | | | |
| *Number of Days Above 90 °F* | 0.0040 | 0.0121* | 0.0148* |
| | (0.0031) | (0.0030) | (0.0036) |
| *Number of Days Above 90 °F ×* | 0.0079 | --- | 0.0119 |
| *Log Doctors Per Capita* | (0.0099) | | (0.0100) |
| *Number of Days Above 90 °F ×* | --- | -0.0274 | -0.0386* |
| *Share with Residential AC* | | (0.0179) | (0.0164) |
| **Age 1-44** | | | |
| *Number of Days Above 90 °F* | 0.0060* | 0.0054 | 0.0042 |
| | (0.0026) | (0.0031) | (0.0032) |
| *Number of Days Above 90 °F ×* | -0.0047 | --- | -0.0071 |
| *Log Doctors Per Capita* | (0.0039) | | (0.0050) |
| *Number of Days Above 90 °F ×* | --- | 0.0005 | 0.0052 |
| *Share with Residential AC* | | (0.0172) | (0.0176) |
| **Age 45-64** | | | |
| *Number of Days Above 90 °F* | 0.0017* | 0.0088* | 0.0038* |
| | (0.0008) | (0.0011) | (0.0021) |
| *Number of Days Above 90 °F ×* | -0.0078 | --- | -0.0074 |
| *Log Doctors Per Capita* | (0.0048) | | (0.0054) |
| *Number of Days Above 90 °F ×* | --- | -0.0179* | -0.0077 |
| *Share with Residential AC* | | (0.0020) | (0.0067) |
| **Age 65+** | | | |
| *Number of Days Above 90 °F* | 0.0034* | 0.0117* | 0.0107* |
| | (0.0012) | (0.0046) | (0.0047) |
| *Number of Days Above 90 °F ×* | -0.0065 | --- | -0.0065 |
| *Log Doctors Per Capita* | (0.0064) | | (0.0059) |
| *Number of Days Above 90 °F ×* | --- | -0.0287* | -0.0240* |
| *Share with Residential AC* | | (0.0095) | (0.0118) |

# Table 9: By Race

| | (1) | (2) | (3) |
|---|---|---|---|
| **White Population** | | | |
| *Number of Days Above 90 °F* | 0.0023* | 0.0076* | 0.0077* |
| | (0.0006) | (0.0017) | (0.0019) |
| *Number of Days Above 90 °F ×* | -0.0002 | --- | 0.0005 |
| *Log Doctors Per Capita* | (0.0021) | | (0.0018) |
| *Number of Days Above 90 °F ×* | --- | -0.0197* | -0.0198* |
| *Share with Residential AC* | | (0.0053) | (0.0059) |
| **Black Population** | | | |
| *Number of Days Above 90 °F* | 0.0131* | 0.0274* | 0.0112* |
| | (0.0041) | (0.0056) | (0.0023) |
| *Number of Days Above 90 °F ×* | 0.0030 | --- | 0.0010 |
| *Log Doctors Per Capita* | (0.0093) | | (0.0044) |
| *Number of Days Above 90 °F ×* | --- | -0.0477* | -0.0302* |
| *Share with Residential AC* | | (0.0126) | (0.0070) |

# Table 10: By Cause of Death

| | (1) | (2) | (3) |
|---|---|---|---|
| **Cardiovascular Disease** | | | |
| *Number of Days Above 90 °F ×* | -0.0003 | --- | 0.0009 |
| *Log Doctors Per Capita* | (0.0037) | | (0.0040) |
| *Number of Days Above 90 °F ×* | --- | -0.0226* | -0.0230* |
| *Share with Residential AC* | | (0.0052) | (0.0069) |
| **Neoplasms** | | | |
| *Number of Days Above 90 °F ×* | 0.0012 | --- | 0.0033* |
| *Log Doctors Per Capita* | (0.0016) | | (0.0011) |
| *Number of Days Above 90 °F ×* | --- | -0.0123* | -0.0149* |
| *Share with Residential AC* | | (0.0028) | (0.0025) |
| **Respiratory Disease** | | | |
| *Number of Days Above 90 °F ×* | -0.0047 | --- | -0.0031 |
| *Log Doctors Per Capita* | (0.0058) | | (0.0067) |
| *Number of Days Above 90 °F ×* | --- | -0.0569* | -0.0526 |
| *Share with Residential AC* | | (0.0255) | (0.0264) |

| | (1) | (2) | (3) |
|---|---|---|---|
| **Infectious Disease** | -0.0059 | -0.0070 | -0.0113 |
| *Number of Days Above 90 °F* | (0.0058) | (0.0147) | (0.0165) |
| *Number of Days Above 90 °F ×* | -0.0251 | --- | -0.0345 |
| *Log Doctors Per Capita* | (0.0220) | | (0.0268) |
| *Number of Days Above 90 °F ×* | --- | -0.0066 | 0.0169 |
| *Share with Residential AC* | | (0.0403) | (0.0484) |
| **Motor Vehicle Accidents** | | | |
| *Number of Days Above 90 °F* | 0.0055 | 0.0077 | 0.0081 |
| | (0.0027) | (0.0070) | (0.0064) |
| *Number of Days Above 90 °F ×* | 0.0048 | --- | 0.0073 |
| *Log Doctors Per Capita* | (0.0078) | | (0.0086) |
| *Number of Days Above 90 °F ×* | --- | -0.0160 | -0.0228 |
| *Share with Residential AC* | | (0.0131) | (0.0156) |

# Outline

# Interpretation

- Health benefits
  - How many >90F deaths per year avoided due to AC?
- Private costs
  - Electricity expenditure due to AC use on >90F days
- External costs
  - Greenhouse gas emissions due to extra electricity generation for AC use on >90F days

## Interpretation

- Implied annual deaths due to days > 90° F
  - 1929-59: 1600
  - 1960-04: 600
  - 1960-04**: 3600 (if 1929-59 coefficient prevailed)

- Implied annual > 90° F deaths avoided due to AC
  - 1960-04: 3300

- Caveat: no age-specific estimates.
  - Longevity gains at least 4 months
  - Also recall significant effects on infants in (Table 8)

# Monetized Estimates of AC's Benefits and Costs

| | Mortality: | | Residential Electricity: | |
|---|---|---|---|---|
| | Number of Deaths Avoided | Monetized Value (Bil. $2006) | Additional Billion kWh (Row B) and Billion Tons CO2 (Row C) | Monetized Value (Bil. $2006) |
| | (1) | (2) | (3) | (4) |
| **A. Estimates of the AC's Health Benefits** | | | | |
| Total Per Year | 3,478 | $6.6 | | |
| | | [1.8] | | |
| Total 1960-2004 | 156,406 | $297.2 | | |
| **B. Estimates of AC's Private Costs** | | | | |
| Total Per Year | --- | --- | 25.7 | $2.9 |
| | | | [4.0] | [1.3] |
| Total 1960-2004 | --- | --- | 1,156 | $129.3 |
| **C. Estimates of AC's External Costs** | | | | |
| Total Per Year | --- | --- | 18.0 | $0.4 |
| Total 1960-2004 | --- | --- | 809 | $17 |

# Implications: US Climate Change

- Will AC help US adapt to temperature-mortality effects of climate change?

- Global climate models: 42 additional annual days >90° F in US by year 2100

- Implied annual >90° F deaths by end of century (fix population at 2004 levels):
  - 1960 AC adoption rate: 59,000
  - 2004 AC adoption rate: <1,000

# Implications: Global Climate Change

- Developing countries?

- India today: 33 annual days >90°F
  - Global climate models: 100 additional days >90°F in India by 2100

# Implications: US versus India

| | United States: 1940 | United States: 2004 | India: 2000s |
|---|---|---|---|
| GDP per capita | $5,500 | $40,000 | $3,000 |
| | | | |
| IMR per 1,000 | 47 | 7 | 58 |
| Deaths per 1,000 | 11.0 | 8.0 | 8.5 |
| Life expectancy | 63 | 80 | 67 |
| | | | |
| Physicians per 1,000 | 1.3 | 2.9 | 0.6 |
| Fraction of population with electricity | 0.74 | 1 | 0.66 |
| Fraction of population with residential AC | 0 | 0.85 | 0.02 |

# Outline

# Conclusions

- First empirical study of adaptation strategies to reduce health costs of extreme heat due to climate change

- Result One
- Result Two
- Air conditioning paradox

# Conclusions

- First empirical study of adaptation strategies to reduce health costs of extreme heat due to climate change
- Result One: Substantial change in temperature-mortality relationship after 1960:
  - Mortality effect of 1 hot day (>90°F): 2.4% $\rightarrow$0.5%
  - Reduced annual fatalities by 3600
  - Less change in mortality effect of cold temperatures
- Result Two
- Air conditioning paradox

# Conclusions

- First empirical study of adaptation strategies to reduce health costs of extreme heat due to climate change

- Result One
- Result Two: residential air conditioning was critical.
  - Explains most temperature-mortality change
  - Electrification and health care access (doctors per capita): no detectable effect on temperature-mortality relationship
  - NB: electrification is prerequisite for air conditioning
- Air conditioning paradox

## Conclusions

- First empirical study of adaptation strategies to reduce health costs of extreme heat due to climate change

- Result One
- Result Two
- Air conditioning paradox:
  - <u>Protects against</u> extreme heat
  - <u>Causes</u> extreme heat via climate change
    - Fossil fuels power air conditioning

# Conclusions

- First empirical study of adaptation strategies to reduce health costs of extreme heat due to climate change

- Result One
- Result Two
- Air conditioning paradox

- Ahead:
  - Welfare consequences of air conditioning?
  - Other mechanisms for adaptation?