Does the Environment still matter? Daily Temperature and Income in the United States

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Overview

Motivation

Source: `https://www.cdc.gov/`

Figure 1: A construction worker on a hot day

Research Question

Do local environmental conditions influence economic well-being in wealthy countries?

Preview of Results

- Total personal income per capita is highest when 24-hour average temperatures are between 9-15°C (48.2-59°F) and declines substantially on hotter days.
- The average productivity of individual days declines roughly linearly by 1.7% for each 1°C (1.8°F) increase in daily average temperature beyond 15°C (59°F).
- Each additional warm day (24-27°C or or 75.2-80.6°F) reduces an average county's total income per capita by roughly \$14.78, with nonfarm income representing roughly \$3.03 of this loss.
- Each additional hot day ($>$30°C or $>$86 °F) reduces total income per capita by \$20.56, equal to 28% of average daily income.

Framework I

- Two sectors: Farming (f) and non-farming (n)
- Each sector j uses capital(K_j) and labor(L_j) to produce output, both factors can be adjusted in response to the daily temperature (T_d).
- Productivities of capital A_j^K and labor A_j^L are treated separately to allow them to respond differently to T_d.

Framework II

- Single day farming output, $q_f(T_d)$, is given by:

$$q_f(T_d) = (A_f^K(T_d)K_f(T_d))^{\alpha}(A_f^L(T_d)L_f(T_d))^{1-\alpha} \tag{1}$$

- Single day non-farming output, $q_n(T_d)$, is given by:

$$q_n(T_d) = (A_n^K(T_d)K_n(T_d))^{\omega}(A_n^L(T_d)L_n(T_d))^{1-\omega} \tag{2}$$

- Annual earnings are given by:

$$\text{Annual Earnings} = \sum_{d=1}^{365}\left[p_f(T_d)q_f^*(T_d) + p_n(T_d)q_n^*(T_d)\right] \tag{3}$$

where, $p_j(T_d)$ is the daily price of each good and $q_j^*(T_d)$ is the optimal quantity of each good produced in response to temperature on a given day.

Framework III

- Defensive Adaption to Temperature:

$$\frac{\partial A_j}{\partial T} = h_j(T_d)(1 - e_j) \tag{4}$$

where $e_j \in [0, 1]$ is the defensive adaption effort in sector j and $h_j(T)$ is the sensitivity of a factor to temperature if no effort was exerted.

- Agents may cope with temperature-induced changes in production by sending or recieving transfers $\tau(T_d)$
- Augmenting equations (3), (4) and $\tau(T_d)$, we get the annual income:

$$\text{Annual Income} = \sum_{d=1}^{365} \left[\underbrace{p_f(T_d)q_f^*(T_d)}_{\text{daily farm income}} + \underbrace{p_n(T_d)q_n^*(T_d)}_{\text{daily nonfarm income}} - \underbrace{c(e^*(T_d))}_{\text{defensive costs}} + \underbrace{\tau^*(T_d)}_{\text{transfers}} \right] \tag{5}$$

Data Sources

- Weather data is obtained from the daily surface data of the National Climatic Data Center (NCDC).
- The Regional Economic Information System (REIS) data published by the Bureau of Economic Analysis (BEA) is used for getting the income and transfers data.

Aggregate Income Model

- Deryugina and Hsiang model annual income as a sum of daily income:

$$Y = \sum_{1}^{365} g(T_d).$$

- They then approximate g step-wise by computing average values of g over temperature buckets indexed by m, denoted $\overline{g(\Omega^m)}$:

$$\begin{aligned} Y &\approx \sum_m \overline{g(\Omega^m)} \sum_{1}^{365} 1[T_d \in \Omega^m] \\ &= \sum_m \overline{g(\Omega^m)}\, \tilde{T}^m. \end{aligned}$$

- This gives a basis for dependence of total income Y on $\{\tilde{T}^m\}$, where $\tilde{T}^m$ is the number of days in which temperature is in bucket m

Augmentation and Regression

- To investigate consequences of this dependence they run a regression on a panel of US counties, augmenting the model to include
  - Autocorrelation
  - Precipitation
  - Lagged weather effects
  - County heterogeneity
  - Non-linear time trends
- That is:

$$Y_{i,t} = \rho Y_{i,t-1} + \sum_m \left[\beta^m \tilde{T}^m_{i,t} + \gamma^m \tilde{T}^m_{i,t-1}\right] + \sum_n \left[\zeta^n \tilde{P}^n_{i,t} + \eta^n \tilde{P}^n_{i,t-1}\right] + \mu_i + \theta_t + \varepsilon_{i,t}$$

- The additional stuff: $\tilde{P}^n$ is the number of days precipitation was in bin n, i is the county, t is the year, μ_i the county fixed effect, θ_t the current year fixed effect, and $\varepsilon_{i,t}$ and error term capturing spatial correlation between counties and within-county autocorrelation

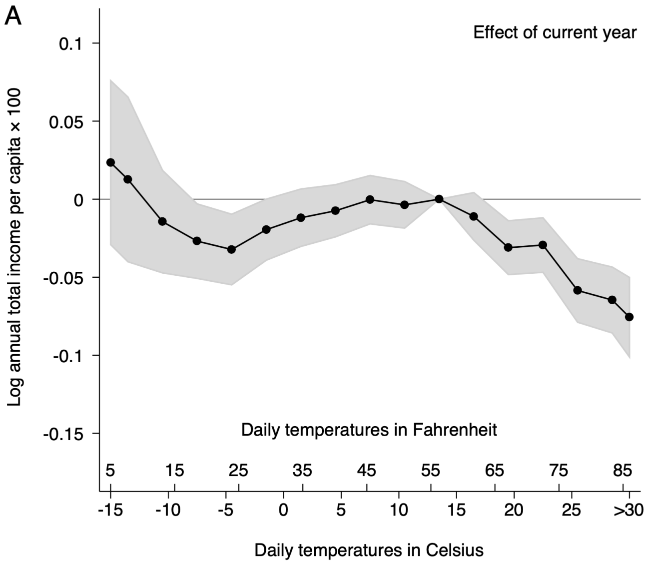
Main Result

Here's the main result

- **In US counties, log personal income increases slightly with temperature, then falls sharply and linearly at temperatures above 15°C.**

Linearizing with 15°C at zero, we find a marginal productivity change of $-1.68\%/^{\circ}C$.

Main Result



- A day at 29°C leads to a 0.065% drop in in income, which is about 23.6% of the daily average

Robustness and Extenstions

They find their model is robust to **temporal displacement**, **earnings** (instead of income), **model specification**, and **measurement levels**

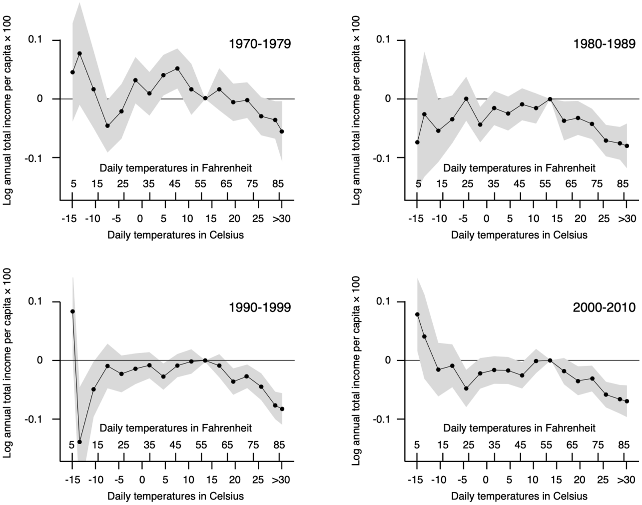
Computing income per person results in an attenuated effects and suggests investigation of farm and non-farm weights, which they consider (we'll get there in "Mechanisms")

They also consider a few extensions to their results:

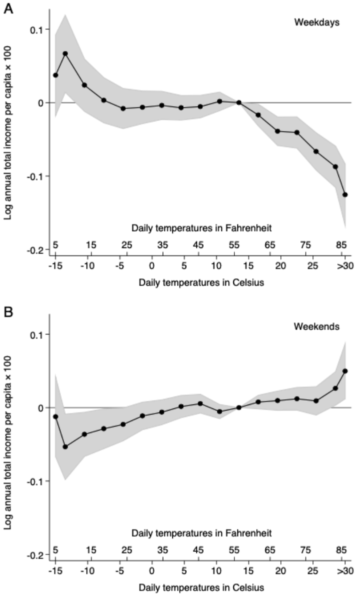
- Stability (or lack of) of adaptation over time
- Effects on income by weekday and weekend day
- Spatial lags between counties and potential income flow
- Dynamic effects of income over time

Adaptation Stability

- Income effects over 4 decades
- Trend is largely stable through time
- Noisy data due to small sample size



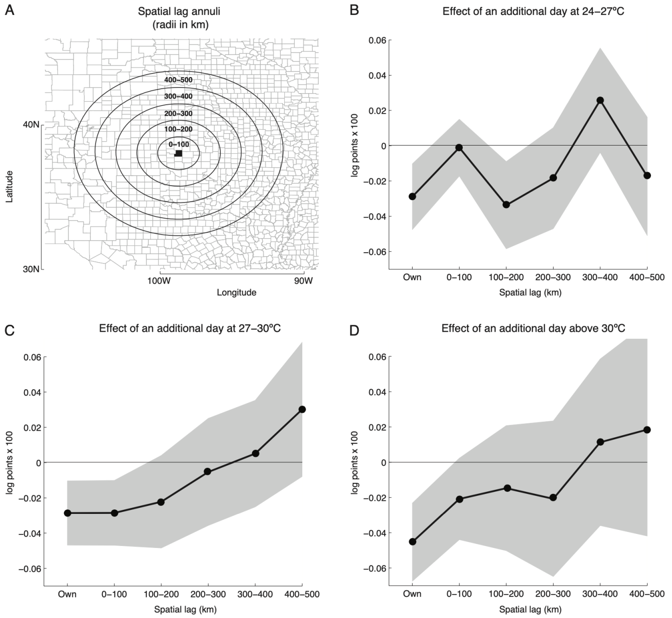
Weekends and Weekdays



- Weekdays have a high reduction with increased daily temperature
  - 0.087% at 27°C
  - Amounts to **22.7%** of daily income if work only happens on weekdays, otherwise **31.8%**
- Weekends are largely flat except for slight increase in hottest bin
- This may be due to increased consumer activity on hot weekend days (trips to mall, etc.)

Spatial Lags

- Measured income effects from surrounding counties
- Expected positive effect
  - Hot days in surrounding counties will cause income to flow from them to the considered county
- Found no statistically significant positive effect
- *Opinion*: Needs to be developed more



Dynamic Income Effects

- Due to autorcorrelation in regression specification, daily temperature costs on income carry through to future days
- They compute the net present value (discounted by a factor $\delta = 0.95$) of a loss in income due to an additional day of temperature in bucket m at moment s in county i (denoted ΔY_{is}^{m}):

$$\text{NPV} = \sum_{t=s}^{\infty} \delta^{s-t} \Delta Y_{is}^{m} = \frac{1}{1-\hat{\rho}\delta}\beta^{m}$$

- We get a discount of the coefficient on $\tilde{T}_{it}^{m}$
- $\hat{\rho}$ is the estimated autoregressive coefficient ≈ 4.62
- Leads to an approximate total cost of a warm or hot day to be 0.5 and 1.3 days worth of income resp.

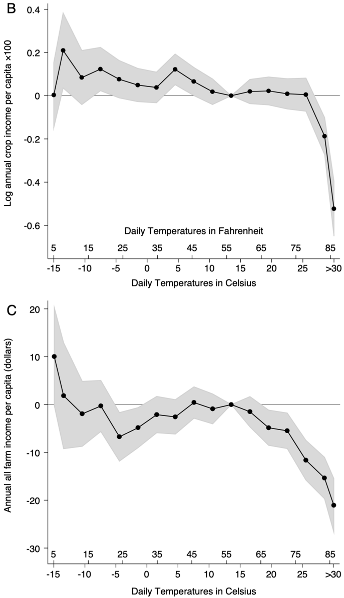
Mechanisms

They also attempt to investigate the mechanisms of the non-linear behavior of income

They investigate income effects from:

- Agricultural income
- Non-agricultural income
- Goverment income transfers, including some specific analysis on:
  - public medical health benefits
  - disaster payments
  - crop insurance

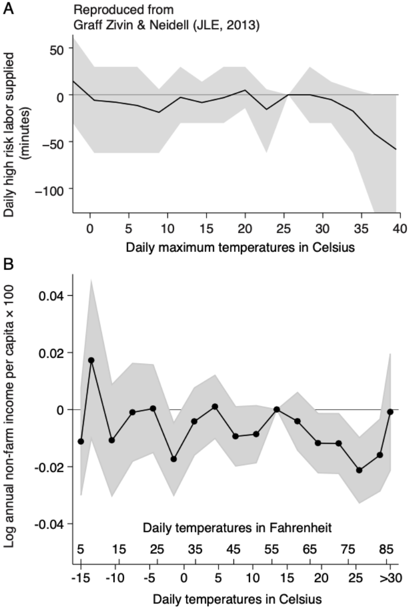
Agricultural Income



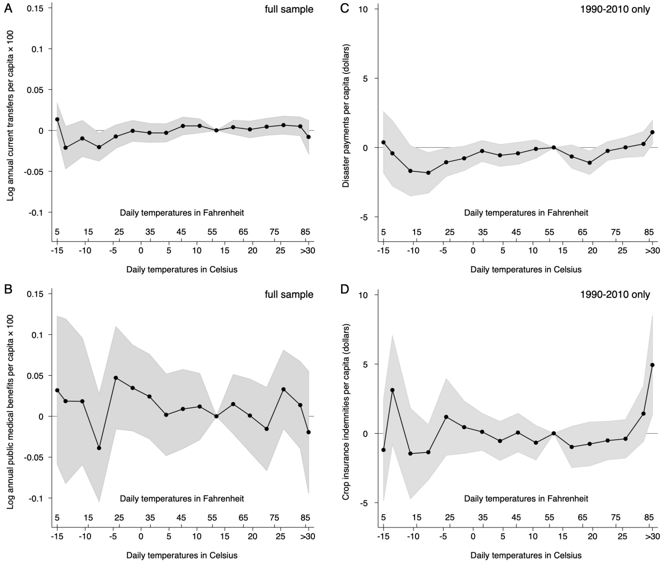
- Clear steep income decline on hot days
- Slightly lower break point than Schlenker and Roberts (2009)
  - Likely due to Schlenker and Roberts using hourly data
  - Results are largely the same
- Higher crop prices do **not** offset decreased production
- A 30°C day leads to 0.523% drop in annual income (worth $\approx$ 2 days)
- Every day above 30°C results in \$21.07 reduction in annual income per person

Non-agricultural Income

- Largely flat at low temperatures
- Reaches the same breakpoint as total income then declines
- Breakpoint from Graff, Zivin, and Neidall (2013) is $\approx 10^{\circ}C$ higher
- The point estimate suggesting an increase in higher temperature is noisy and not significant
- A day at 25°C causes a **7.8%** reduction in income from the day

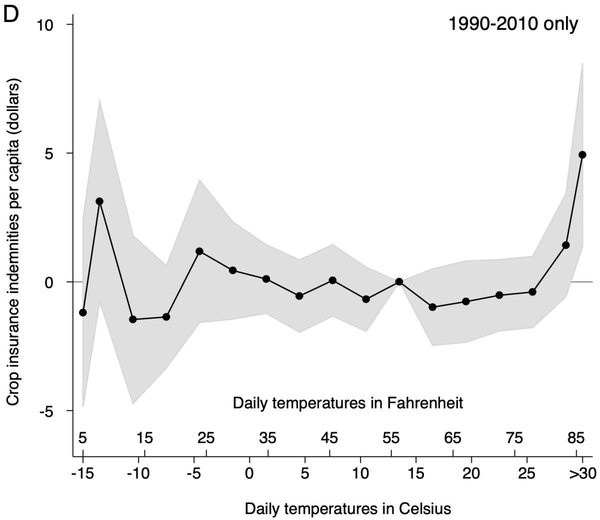


Governmental Transfers



- Daily temperature appears to have no effect on total current transfers
- Still no pattern in transfers related to public health
  - Goes against expectations by Deryugina and Hsiang
- No pattern in disaster payments but some increase in crop insurance payments

Governmental Transfers for Crop Insurance



- Crop payments increase steeply for days exceeding 27°C
- Each day above 30°C leads to $5 per capita in crop insurance
- Without crop insurance, non-farm incomes would be 25% lower in highest temperature bucket

Two Thought Experiments

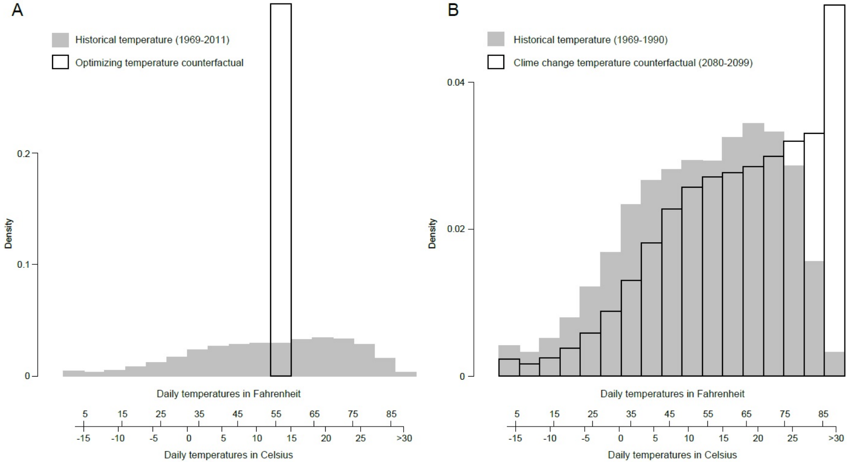


Figure 3: Two Thought Experiments

Temperature as a component of geography

- Counties set their temperature to $12 - 15^0 C$ each day.
- Scenario is interpreted as relaxing the constraint imposed by geography.
- Historic simulation closely mimics the observed national income trajectory.
- US income would grow on average 4.05% per year if counties could optimize temperature, compared to 2.36% in historic simulation.
- It takes one decade for confidence intervals of the simulations to separate completely.

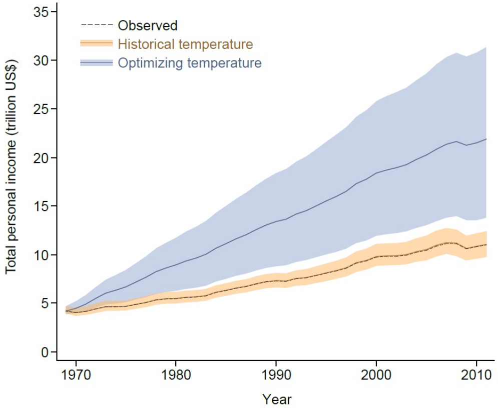


Figure 4: Comparison of observed nationally aggregated total personal income (dashed black) with model predictions.

Climate change

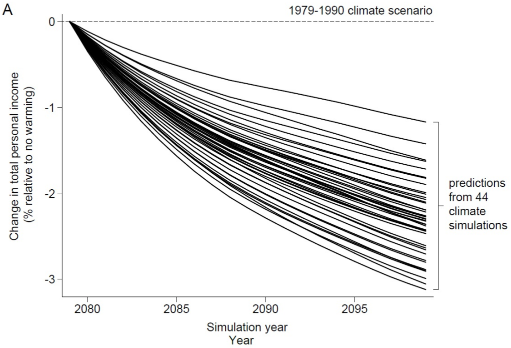


Figure 5: Estimated change in total personal income in a "business as usual" climate change scenario (RCP 8.5) relative to 1970-1990 conditions.

- Each line represents the estimated effect of warming using one of the 44 model simulations..
- Average incomes would be lower by 2.31% relative to 1969-1990 baseline.
- Full range of projections spans from -3.12% to -1.17%.
- Inner 36 projections (90% of simulations) span from -2.90% to -1.72%.

Climate change

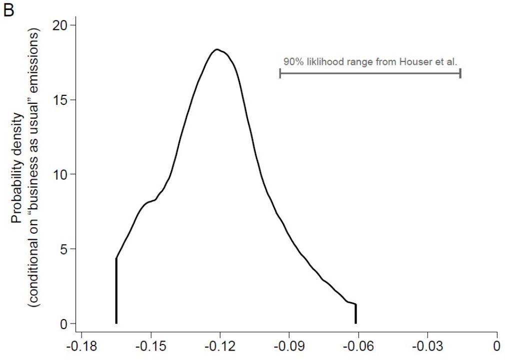


Figure 5: Estimated distribution for the growth rate effect of "business as usual" climate change scenarios shown in Panel A.

- The probability distribution of impacts that are expected if emissions follow the "business as usual" scenario.
- Based on median estimate, income growth will slow down by 0.12 percentage points per year.
- Central 50% of probability mass spans from -0.13 to -0.11 percentage points.
- The inner 90% of mass spans from -0.15 to -0.06 percentage points..

Concluding remarks

Even after full adjustment to environmental conditions, daily temperature affects production possibility frontier of counties in the US.

- This suggests that even in a wealthy economy the costs of adaptation prevent environmental issues from being fully utilized.

But it still remains likely that poorer economies are more affected by environment than wealthy ones.

The authors provide two hypotheses to explain apparent differences between environmental sensitivities of rich and poor countries:

- Countries being poor and having their income tightly coupled to the environment is correlated but not causal.
- Reverse causality is playing a role in generating observed patterns