The Light of Life: The Effects of Sunlight on Suicide

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Research Questions

- Does sunlight exposure affects mental well-being and suicide?

- How does solar geoengineering affect suicide?

Why Suicides?

- "Death of Despair"
  - Declining life expectancy (Case and Deaton 2020)

- ↑ 30% in 2000–2018
  - The only leading 10 causes of death that is on the rise
  - 12.2m thought, 3.2m planned, 1.2m attempted, 46k died in 2020 (CDC)
  - > HIV, malaria, breast cancer, conflicts and other violence, globally

- New focus on environmental changes
  - Temperature (Carleton 2017; Burke et al. 2018)
  - Air pollution (Braithwaite et al. 2019)

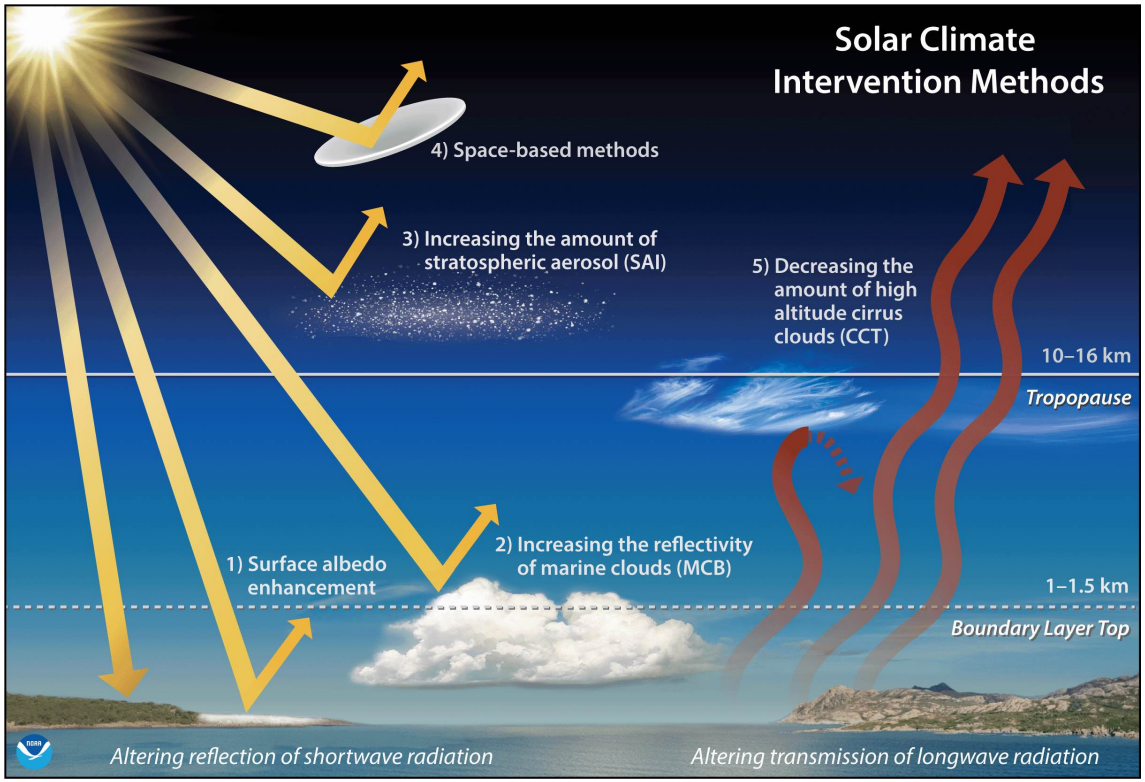
Why Sunlight?

- Convincing evidence is (surprisingly) thin
  - Seasonal Affective Disorder peaks in winter, Jan.
  - Suicide peaks in late spring/early summer, May. Figure
  - Thin and mixed evidence
    - $\varnothing$ (Kadotani et al. 2014; White et al. 2015; Gao et al. 2019; Markris et al. 2021)
    - $\oplus$ (Papadopoulos et al. 2005; Vyssoki et al. 2014)

- Misleading public campaign
  - Insufficient sunlight exposure and vitamin D deficiency are prevalent ($\approx$40% in US and EU)
  - Related to 340k deaths in US and 480k deaths in EU due to cancer, cardiovascular diseases, and metabolic syndrome

Why Solar Geoengineering?

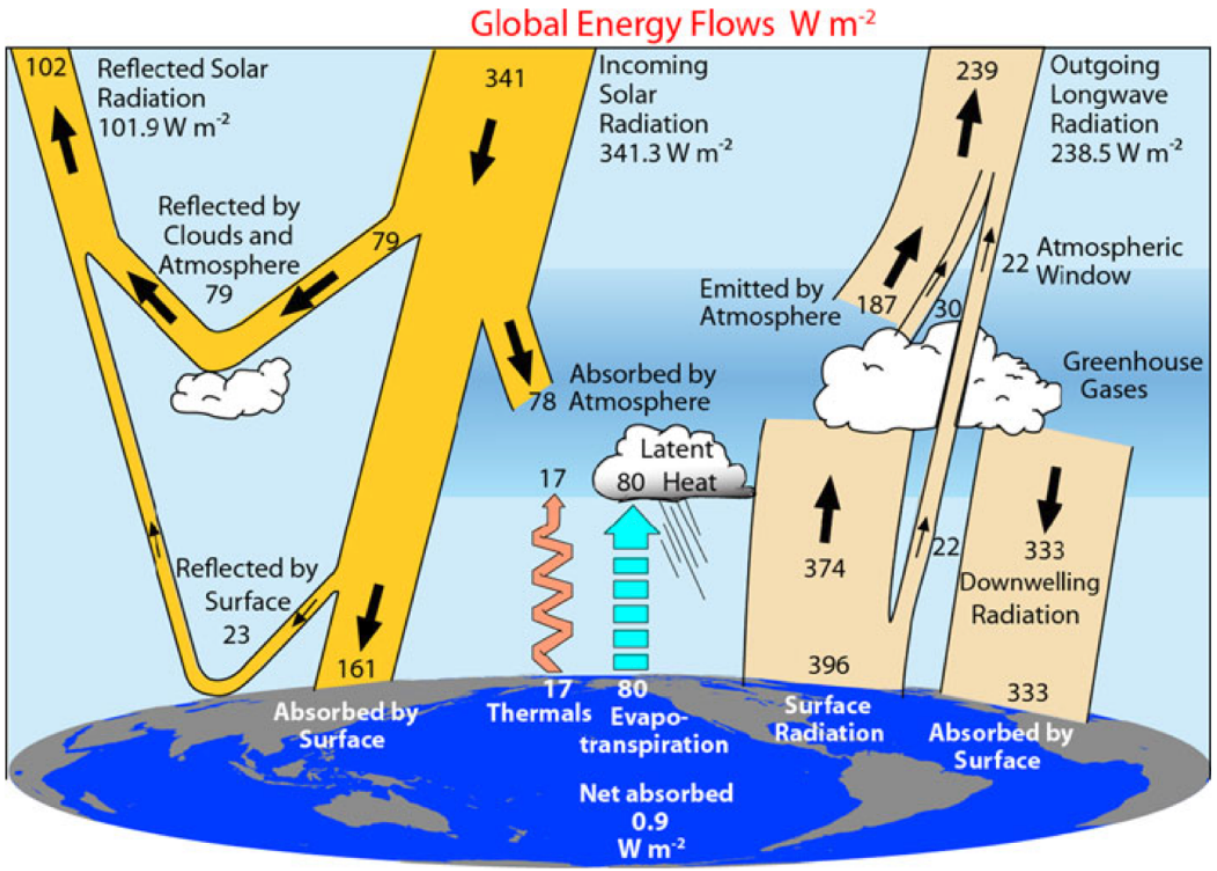
- Increasing interests in solar geoengineering to achieve the Paris Agreement ($\Delta T \leq 1.5$ °C)



- But large uncertainties w.r.t. impacts on human well-being

Significance of This Study

- Using **solar insolation** as a direct measure of sunlight exposure vs. indirect daylight duration



Trenberth and Fasullo (2012) Surv. Geophys.

Significance of This Study

- Large longitudinal sample
  - 3,107 US counties in 1979–2004
  - N = 444,861
- Control for a large set of confounding variables
  - Adjust for county-by-month, state-by-year effects
  - Literature exclusively on time-series, finding positive effects
- First study to project the effects of solar geoengineering

Preview of Results

- Insufficient sunlight increases suicides
  - 1SD ↓ in sunlight ↑ suicides by 6.99%
  - The effects are comparable to other major risk factors

- Solar geoengineering can increase suicides
  - Sunlight alone ↑ suicides by [1,590, 3,500](95%CI)
  - Net temperature ↑ suicides by $[781, -7,720]$(95%CI)

Data

- Suicide data
  - Multiple Cause-of-death Mortality Data from the National Vital Statistics System
  - 1968–2004
  - County × month × year

- Sunlight
  - The North America Land Data Assimilation System Daily Sunlight data by CDC
  - 1979–2011

Empirical Framework

- Estimating the effects of sunlight exposure on suicide rate

$$Y_{csmt} = \alpha + \sum_{l=k}^{K} \left[\beta_l \ln(Sunlight)_{c(m-l)t} + \gamma_l T_{c(m-l)t} + \lambda_l P_{c(m-l)t} \right] + \mu_{cm} + \tau_{st} + \varepsilon_{csmt}$$

  - Y_{csmt} = suicide rate (per 100K) in county c, state s, month m, year t
  - $Sunlight$ = average daily solar insolation (in KJ/m^2)
  - T = temperature
  - P = precipitation

Table: Effect of Sunlight on Suicide Rate

	(1)	(2)	(3)	(4)	(5)
$\ln(Sunlight)_0$	-0.049**	-0.052**	-0.045*	-0.060***	-0.043*
	(0.022)	(0.022)	(0.025)	(0.022)	(0.023)
$\ln(Sunlight)_{-1}$					
$\ln(Sunlight)_{-2}$					
$\ln(Sunlight)_1$					
Fixed effects	cm + st	cm + t	cm + mt	cm + t + state trend	cm + ct

Notes: FE: c = county; s = state; m = month; t = year. SE clustered at the county-level. Mean suicide rate = 0.955 per 100K.

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$\ln(Sunlight)_{-1}$	-0.085***	-0.083***	-0.086***	-0.093***	-0.077***
	(0.024)	(0.024)	(0.025)	(0.024)	(0.024)
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	(0.022)	(0.021)	(0.023)	(0.021)	(0.022)
$\ln(Sunlight)_1$	0.010	0.006	0.002	-0.004	0.017
	(0.024)	(0.023)	(0.025)	(0.023)	(0.024)
Fixed effects	cm + st	cm + t	cm + mt	cm + t + state trend	cm + ct

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$\text{Effect}_{0,-1}$	6.99%	7.10%	6.84%	7.94%	6.27%
Fixed effects	cm	cm	cm	cm + t	cm
	+ st	+ t	+ mt	+ state trend	+ ct

Notes: FE: c = county; s = state; m = month; t = year. SE clustered at the county-level. Mean suicide rate = 0.955 per 100K. $\text{Effect}_{0,-1}$ by 1SD ↓ in sunlight (AZ→VT).

Sunlight vs. Temperature

	(1)	(2)	(3)	(4)	(5)
$\ln(Sunlight)_0$	-0.049**	-0.052**	-0.045*	-0.060***	-0.043*
	(0.022)	(0.022)	(0.025)	(0.022)	(0.023)
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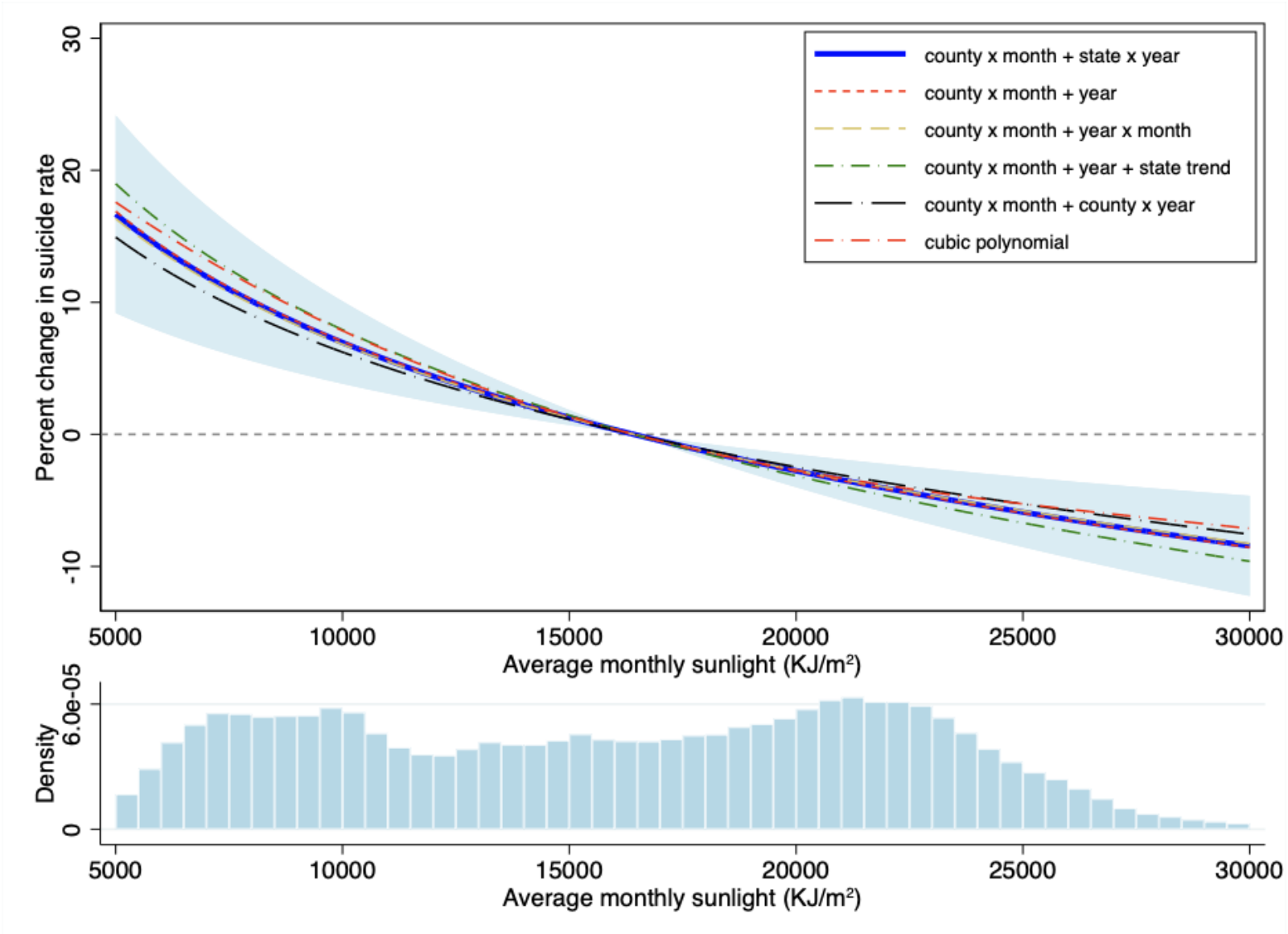
	(0.024)	(0.024)	(0.025)	(0.024)	(0.024)
$Temp_0$	0.008***	0.009***	0.009***	0.008***	0.008***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
$Temp_{-1}$	-0.002**	-0.001	-0.001	-0.002**	-0.002**
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
$\text{Effect}_{0,-1}$ sun	6.99%	7.10%	6.84%	7.94%	6.27%
$\text{Effect}_{0,-1}$ temp	5.73%	7.64%	7.64%	5.73%	5.73%
Fixed effects	cm	cm	cm	cm + t	cm
	+ st	+ t	+ mt	+ state trend	+ ct

Notes: FE: c = county; s = state; m = month; t = year. SE clustered at the county-level. Mean suicide rate = 0.955 per 100K. $\text{Effect}_{0,-1}$ by 1SD Δ in sunlight (AZ→VT) and temp (9.1°C).

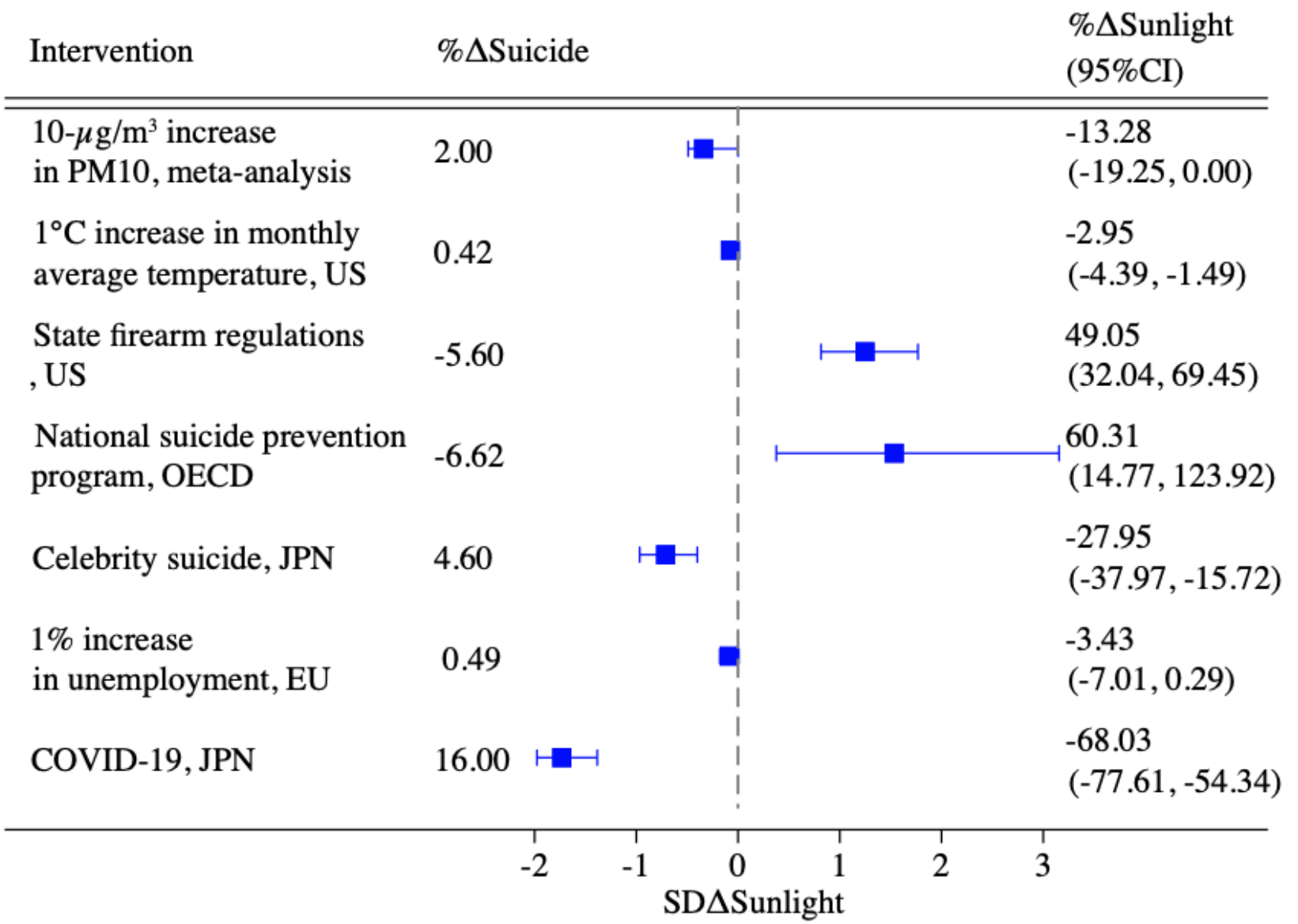
Effects of Sunlight on Suicides



Robustness

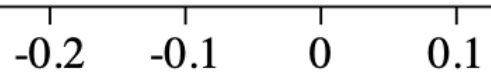
- Alternative outcomes ▸▸ Table
  - ln(rate + 1)
  - ln(count + 1)
  - Inverse hyperbolic sine
  - Count model
- Alternative specifications
  - 3rd order polynomials
  - Non-parametric bins for each decile ▸▸ Figure
- Alternative clustering levels
  - county+ year, county + state-year, county + year, state ▸▸ Table

Comparisons to Other Interventions

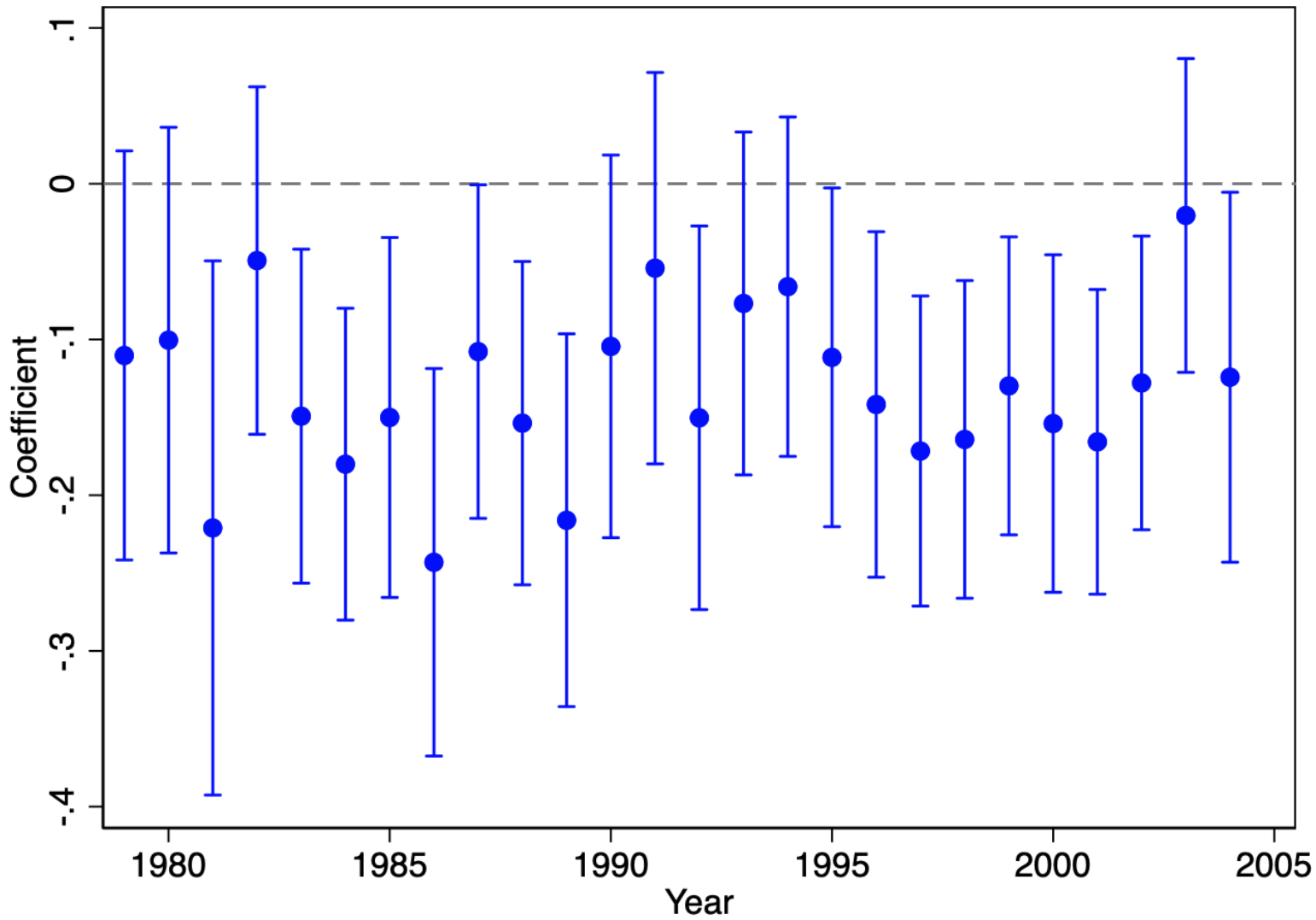


Heterogeneities

Sample	Mean	Estimate (95%CI)
Baseline	0.95	-0.13 (-0.19, -0.07)
Above median sunlight	1.03	-0.13 (-0.23, -0.04)
Below median sunlight	0.88	-0.13 (-0.20, -0.06)
Above median temperature	1.04	-0.14 (-0.24, -0.05)
Below median temperature	0.87	-0.12 (-0.20, -0.04)
Above median income	0.92	-0.18 (-0.25, -0.10)
Below median income	1.01	-0.06 (-0.16, 0.04)
Above median AC adoption	1.00	-0.10 (-0.20, -0.01)
Below median AC adoption	0.91	-0.16 (-0.24, -0.09)
Above median gun ownership	1.03	-0.12 (-0.20, -0.03)
Below median gun ownership	0.88	-0.16 (-0.24, -0.07)
Male nonviolent	0.21	-0.08 (-0.12, -0.04)
Male violent	1.17	-0.14 (-0.24, -0.04)
Female nonviolent	0.16	-0.04 (-0.08, -0.01)
Female violent	0.22	0.00 (-0.04, 0.04)



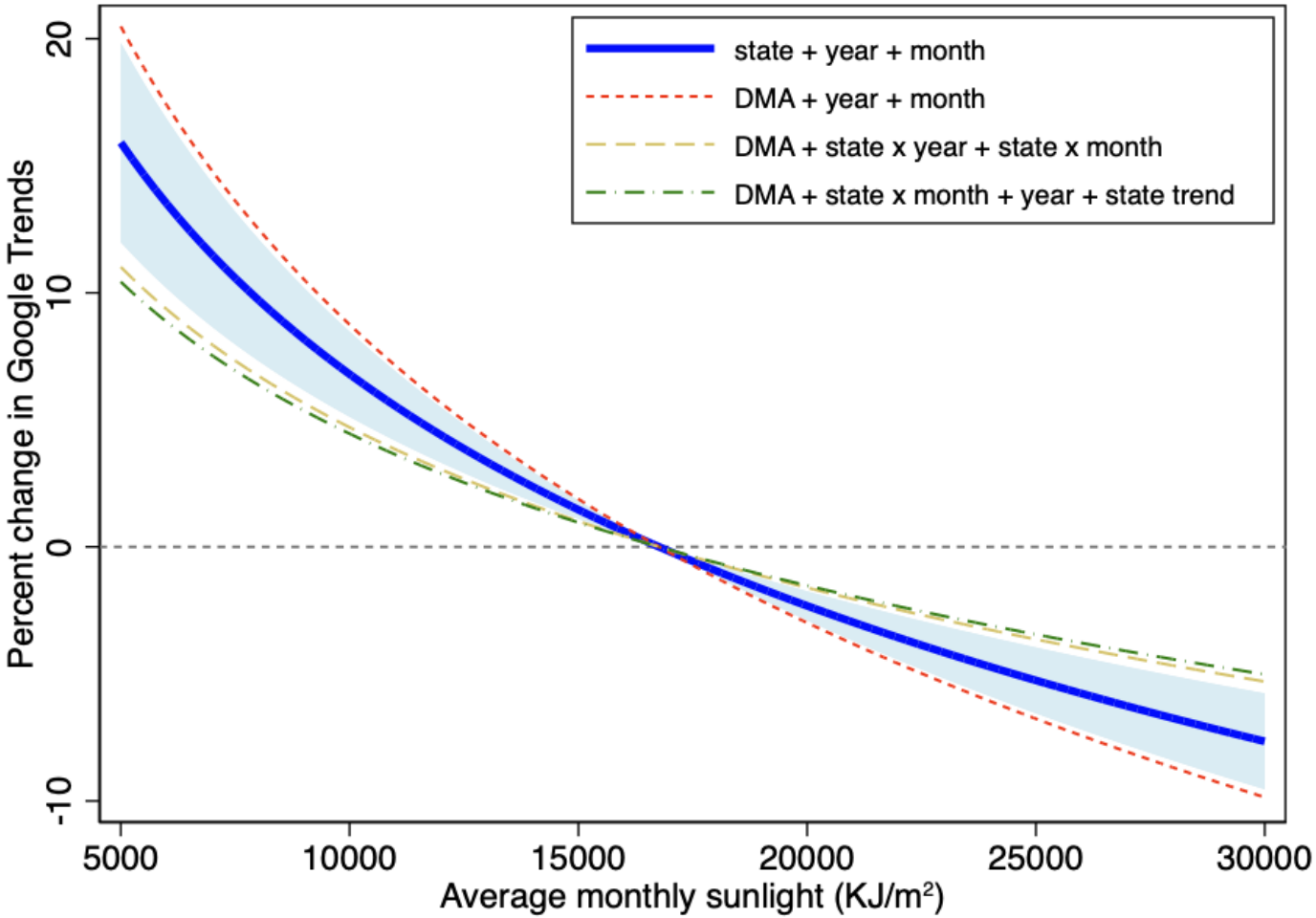
Adaptation over Time



Data

- Google Trends
  - Report search volumes (indexed) on Google
  - State or Designated Marketing Area (DMA) level Map
  - 2004–2011, monthly
  - The set of depressive language terms (Burke et al. 2018)
    - addictive, alone, anxiety, appetite, attacks, bleak, depress, depressed, depression, drowsiness, episodes, fatigue, frightened, lonely, nausea, nervousness, severe, sleep, suicidal, suicide, and trapped

Effects on Google Trends



▸▸ Table

Climate vs. Weather Effects

$$
\begin{aligned}
Y_{csmt} =& \alpha + \sum_{l=k}^{K} \Bigg\{ \beta_l \underbrace{\ln(\overline{Sunlight})_{c(m-l)}}_{\text{climate effect}} \\
&+ \delta_l \underbrace{\left[\ln(Sunlight)_{c(m-l)t} - \ln(\overline{Sunlight})_{c(m-l)} \right]}_{\text{weather effect}} \\
&+ \gamma_l T_{c(m-l)t} + \lambda_l P_{c(m-l)t} \Bigg\} + \nu_c + \mu_m + \tau_{st} + \varepsilon_{csmt}
\end{aligned}
$$

- $\overline{Sunlight}_{cm}$ = county-month average sunlight
- β = The effects of an *anticipated* shift in sunlight, i.e., climate effect
- δ = The effects of an *unanticipated* shock to sunlight, i.e., weather effect

▸▸ Table

Projected Impacts of Solar Geoengineering

- Projection for 2030–2100

$$\sum_{t=2030}^{2100} pop_t \times \beta \times \Delta \ln(Sunlight)_t$$

  - pop = projected population (in 100K)
  - β = the climate effect of sunlight
  - $\Delta \ln(Sunlight)_t$ = negative radiative forcing gap to achieve $\Delta T_t = 1.5$ °C under BAU CO_2 emissions (47 Gt/year)
    - 1 °C/1,300 Gt(CO_2) (Lawrence et al. 2018)
    - 9.6×10^{-4} (W/m^2)/Gt(CO_2) (IPCC 2013)

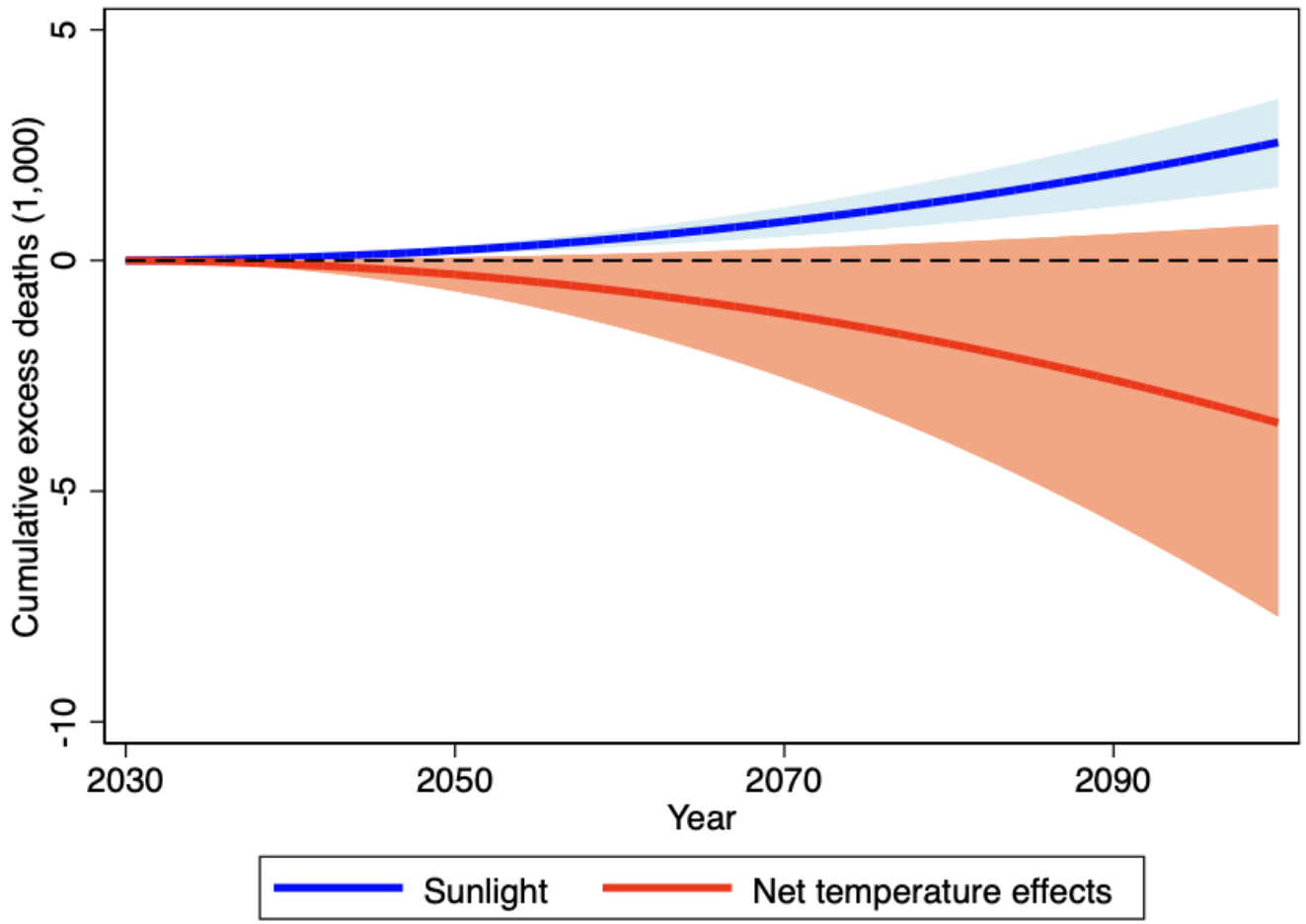
Projected Impacts of Solar Geoengineering

- Projection for 2030–2100

$$\sum_{t=2030}^{2100} pop_t \times \gamma \times \Delta T_t$$

  - pop = projected population (in 100K)
  - γ = the climate effect of temperature (Gammans 2020)
  - ΔT_t = reduced temperature to achieve $\Delta T_t = 1.5$ °C under BAU CO_2 emissions (47 Gt/year)
    - 1.54 °C in 2030
    - 4.21 °C in 2100

Projected Impacts of Solar Geoengineering



- Sunlight effect = 2,560 (95% CI: 1,590, 3,500) by 2100
- Net = $-3,520$ (95% CI: $-7,720$, 781) by 2100 ⏩ Simulation

Conclusions

- The greater exposure to sunlight has a preventive impact on suicide along with other health benefits
  - The current public health advice focuses only on harms of sunlight exposure, e.g., skin cancer

- The solar geoengineering needs to better balance the potential benefits and harms of solar radiation

Appendix

Seasonality in Suicide Rates

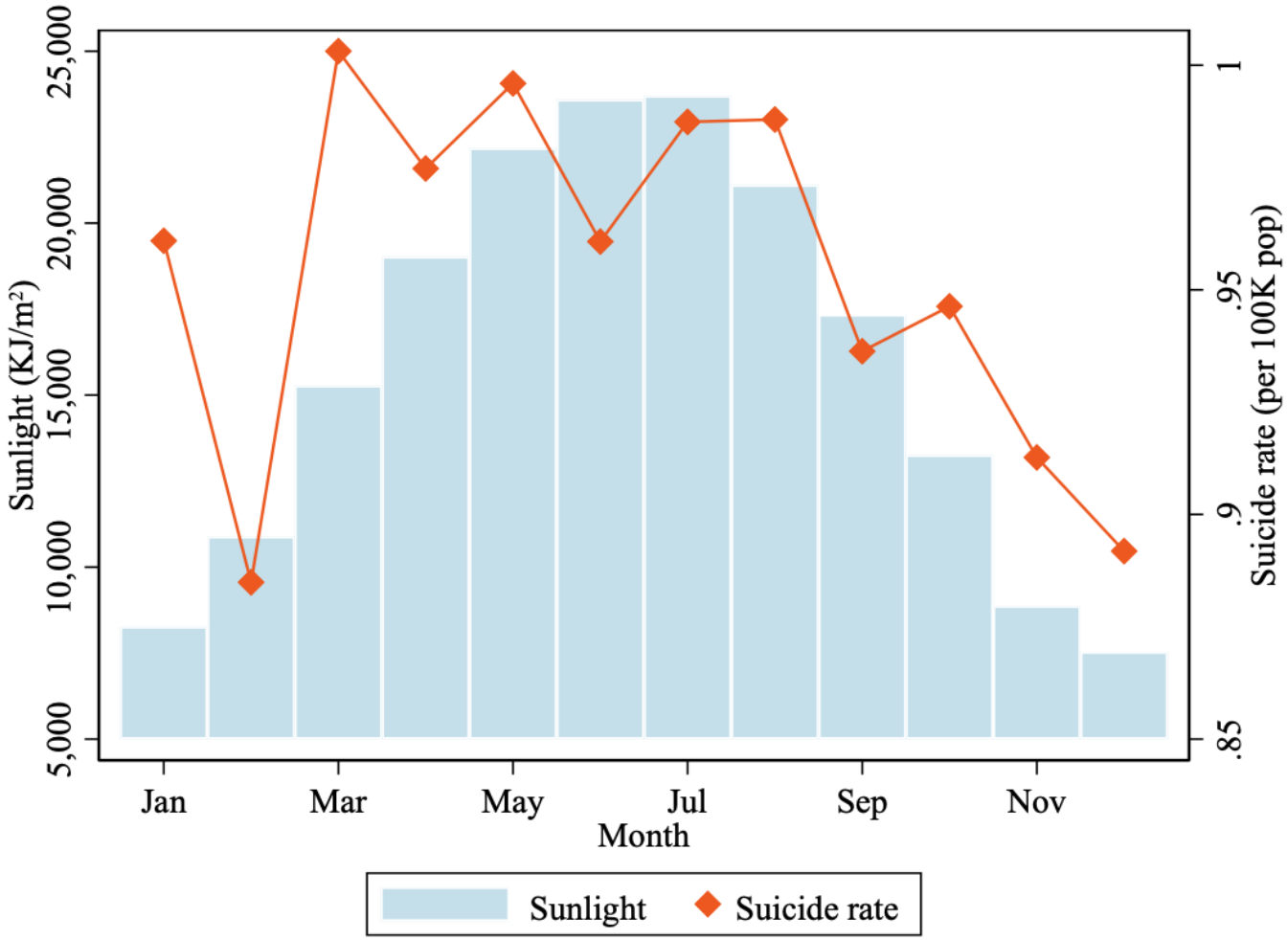


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Table: Robustness to Alternative Levels of Clustering the Standard Errors

	(1)	(2)	(3)	(4)
$\beta_0 + \beta_{-1}$	-0.134***	-0.134***	-0.134***	-0.134***
se($\beta_0 + \beta_{-1}$)	(0.031)	(0.031)	(0.041)	(0.028)
$p(\beta_0 + \beta_{-1})$	[0.000]	[0.000]	[0.003]	[0.000]
Clustering	county	county + state-year	county year	state

Notes: This table tests the robustness of the effects of sunlight on suicide rates based on the main but at different levels of clustering the standard errors.

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Table: Robustness to a Set of Controls

	(1)	(2)	(3)	(4)
$\beta_0 + \beta_{-1}$	-0.072***	-0.115***	-0.097***	-0.134***
se($\beta_0 + \beta_{-1}$)	0.028	0.028	0.030	0.031
$p(\beta_0 + \beta_{-1})$	0.009	0.000	0.001	0.000
Controls	Sunlight	Sunlight + Temp.	sunlight + Precip.	Sunlight Temp + Precip.

Notes: This table shows the effects of sunlight with various sets of other controls.

Table: Estimated Effects of Sunlight on Temperature

	(1)	(2)	(3)	(4)	(5)	(6)
	Weighted			Unweighted		
ln(Sunlight)			2.633***			1.479***
			(0.177)			(0.079)
Precipitation		-2.319***	-0.543***		-2.182***	-1.173***
		(0.236)	(0.193)		(0.060)	(0.072)
R^2	.9727	.9728	.9731	.9708	.9709	.9710
ΔTemp (°C)			-1.328			-.732
ΔTemp (SD)			-0.144			-0.074

Notes: This table presents the estimated effects of sunlight and precipitation in addition to the county-by-month and state-by-year fixed effects. The last two rows indicate the effect of a 1SD decrease in sunlight on temperature in °C and SD, respectively.

Table: Robustness to Alternative Outcomes

	(1)	(2)	(3)	(4)
	ln(rate+1)	ln(count+1)	IHS	Count
$\ln(Sunlight)_0$	-0.049**	-0.015	-0.038**	-0.052**
	(0.022)	(0.011)	(0.015)	(0.024)
$\ln(Sunlight)_{-1}$	-0.085***	-0.019*	-0.055***	-0.089***
	(0.024)	(0.011)	(0.016)	(0.025)

Notes: All regressions control for county-month and state-year fixed effects. Regressions are weighted by population in Columns (1) and (3), while Column (2) additionally controls for the log of population, and Column (4) is estimated by the Poisson regression that includes the population as an exposure variable.

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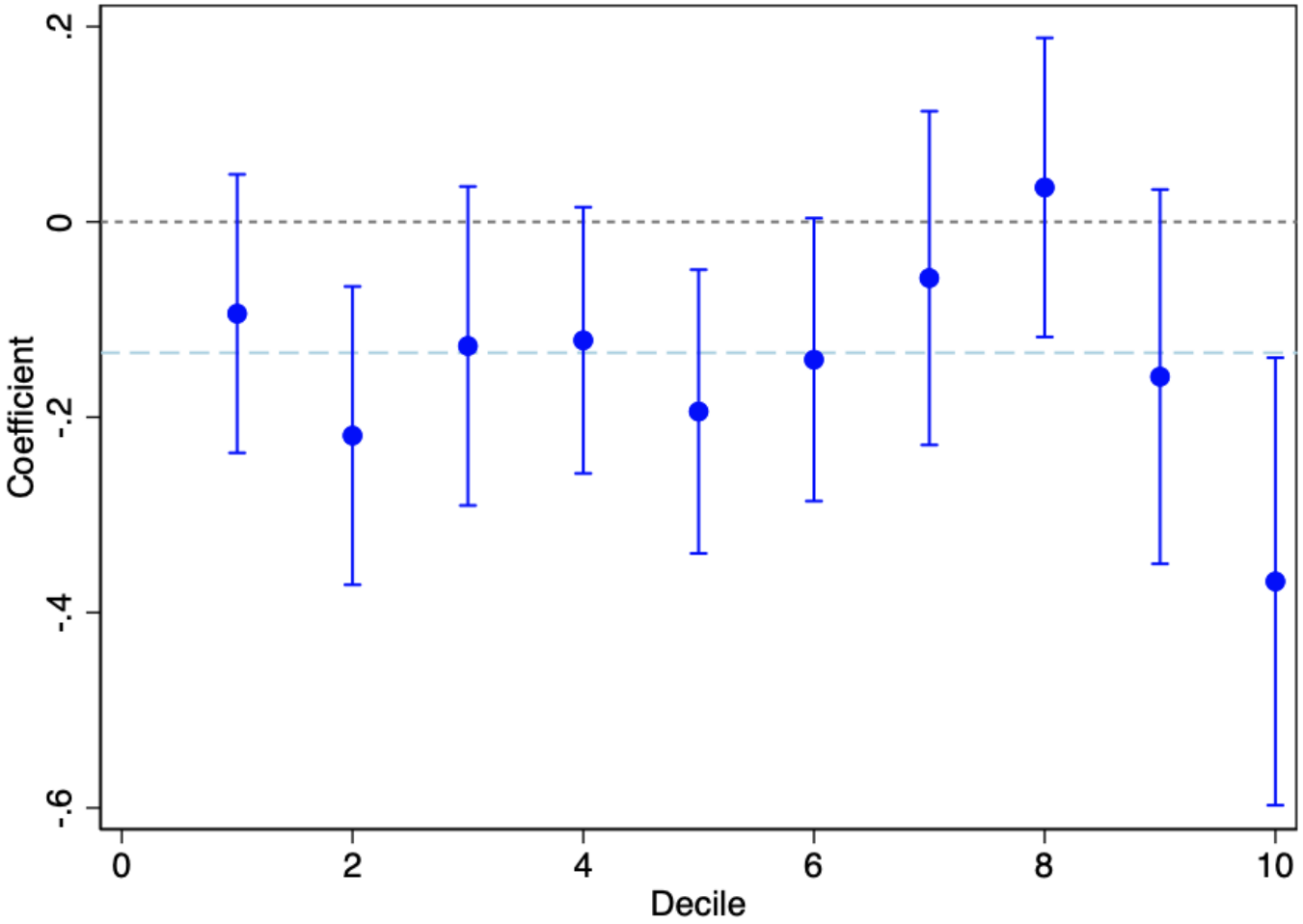
Nonparametric Model



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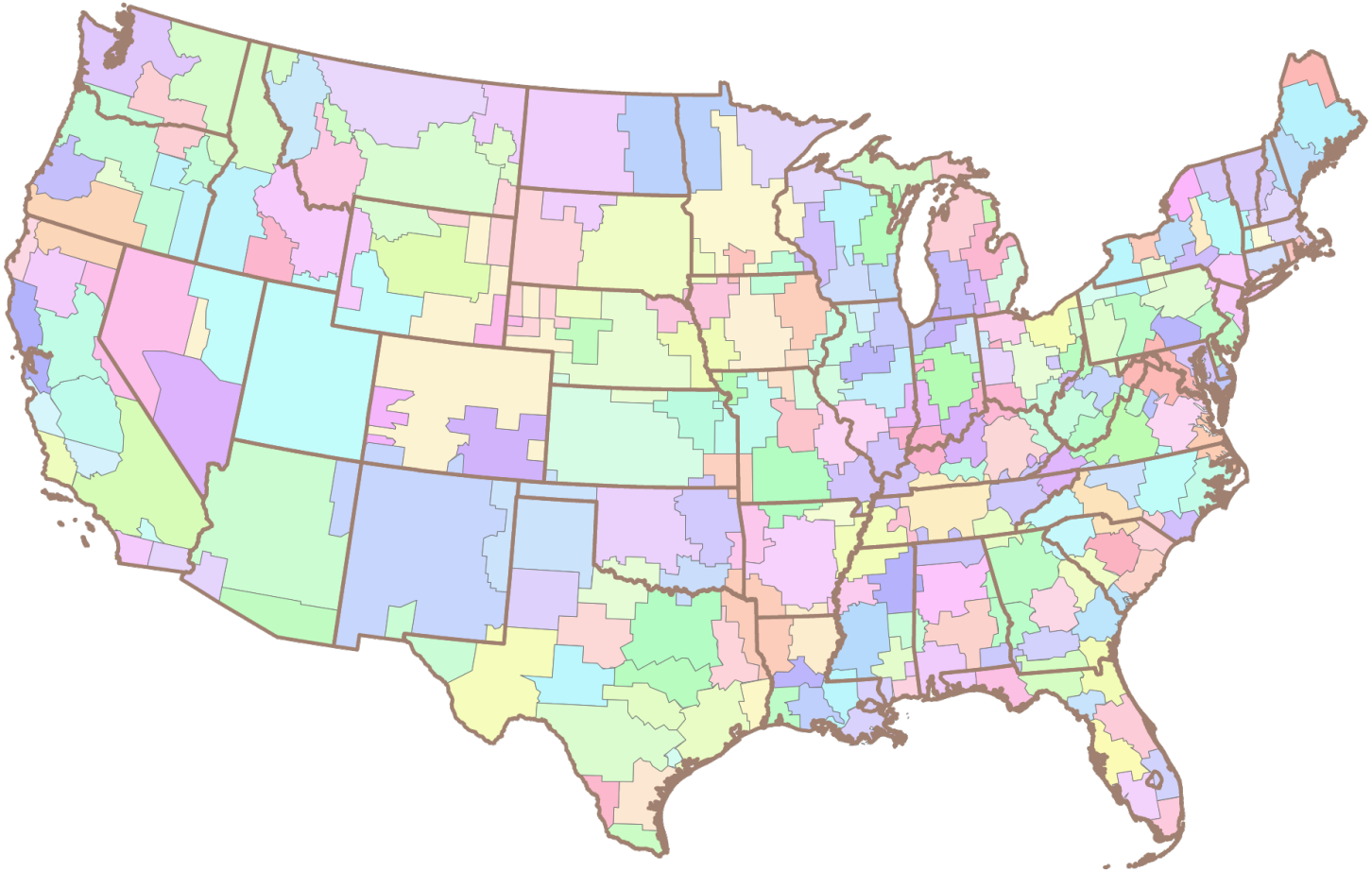
210 Designated Marketing Areas



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Effects on Google Trends

	(1)	(2)	(3)	(4)
Panel A: All keywords				
Effect	-8.464***	-10.896***	-5.860**	-5.549**
	(1.038)	(2.608)	(2.817)	(2.306)
N	4655	8796	8774	8774
Panel B: depression, depressed, depress				
Effect	-8.881***	-12.557***	-8.697	-7.746
	(2.426)	(4.805)	(6.388)	(6.158)
N	4655	8785	8763	8763
Panel C: suicide, suicidal				
Effect	-4.584***	-7.545	-5.507	-5.287
	(1.193)	(4.632)	(5.278)	(5.006)
N	4655	8697	8675	8675
Region type	State	DMA	DMA	DMA
Fixed effects	State	DMA	DMA	DMA
	+ yr	+ yr	+ state × yr	+ state × mo
	+ mo	+ mo	+ state × mo	+ state trend

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Table: Climate vs. Weather

	(1)	(2)	(3)	(4)	(5)
Climate (β)	-0.078***	-0.070***	-0.081***	-0.078***	-0.076***
	(0.017)	(0.018)	(0.018)	(0.017)	(0.017)
Weather (δ)	-0.124***	-0.129***	-0.130***	-0.146***	-0.115***
	(0.030)	(0.033)	(0.029)	(0.029)	(0.030)
Fixed effects	County + month + state × year	County + month × year	County + month + year	County + month + year + state-trend	County + month + county × year

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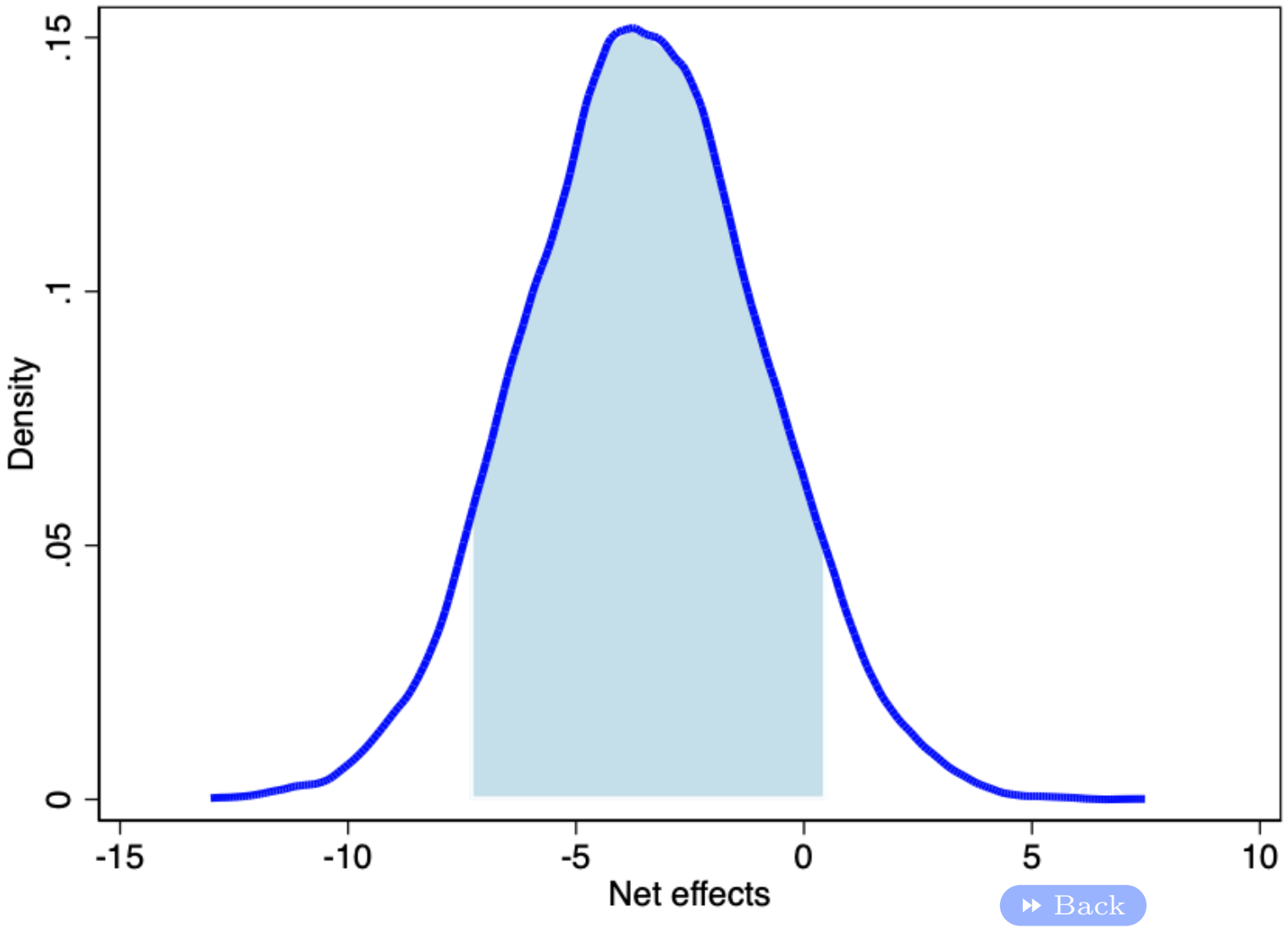
Simulated Net Effects of Solar Geoengineering



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