

Reducing Health Risks from Extreme Temperatures in the Elderly: The Role of Solar Photovoltaics

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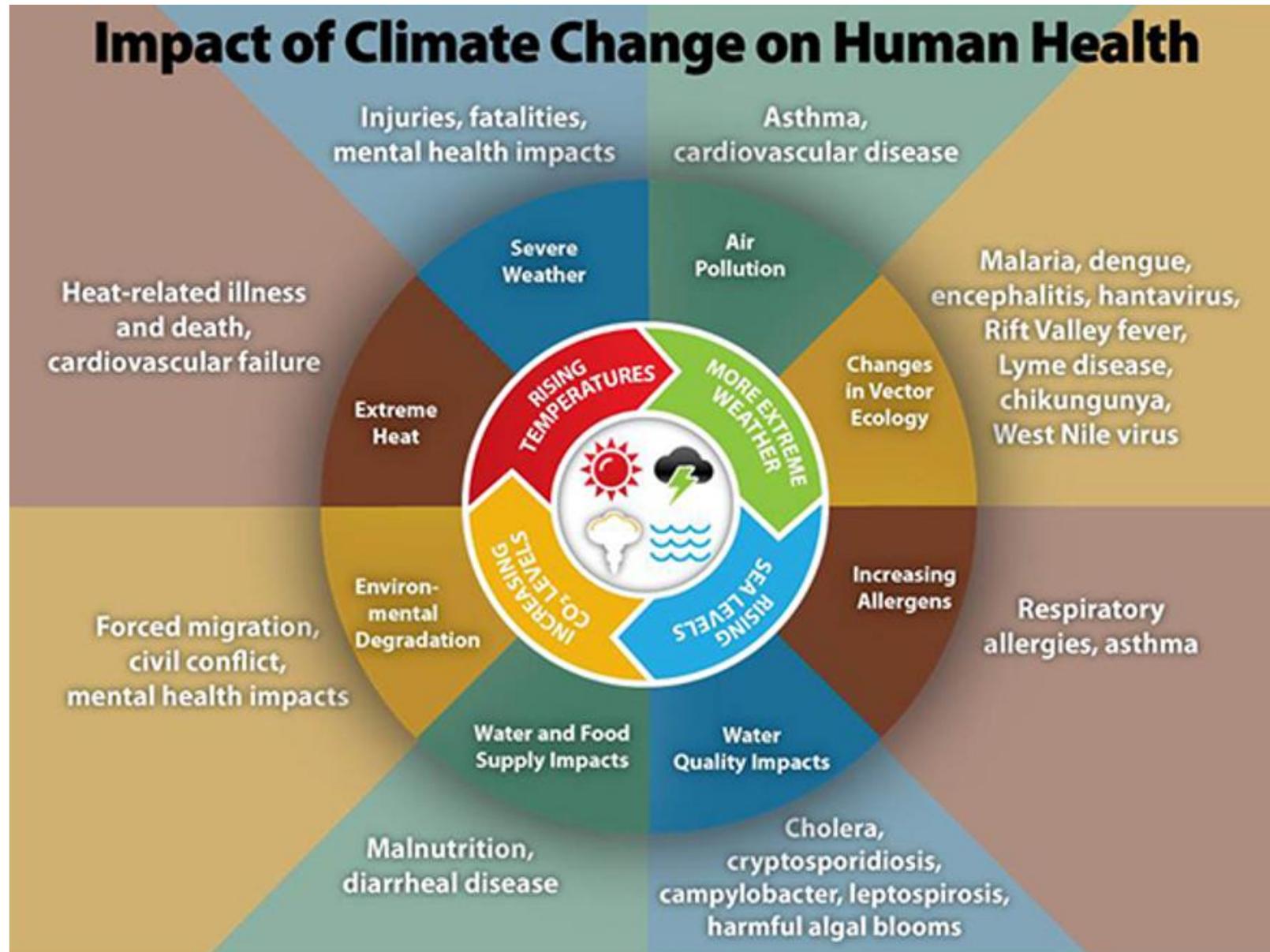


Outline

- Introduction
 - Background
 - Research Objective
 - Summary of Findings
- Empirical Methodology
- Data
- Estimation Results
- Concluding Remarks

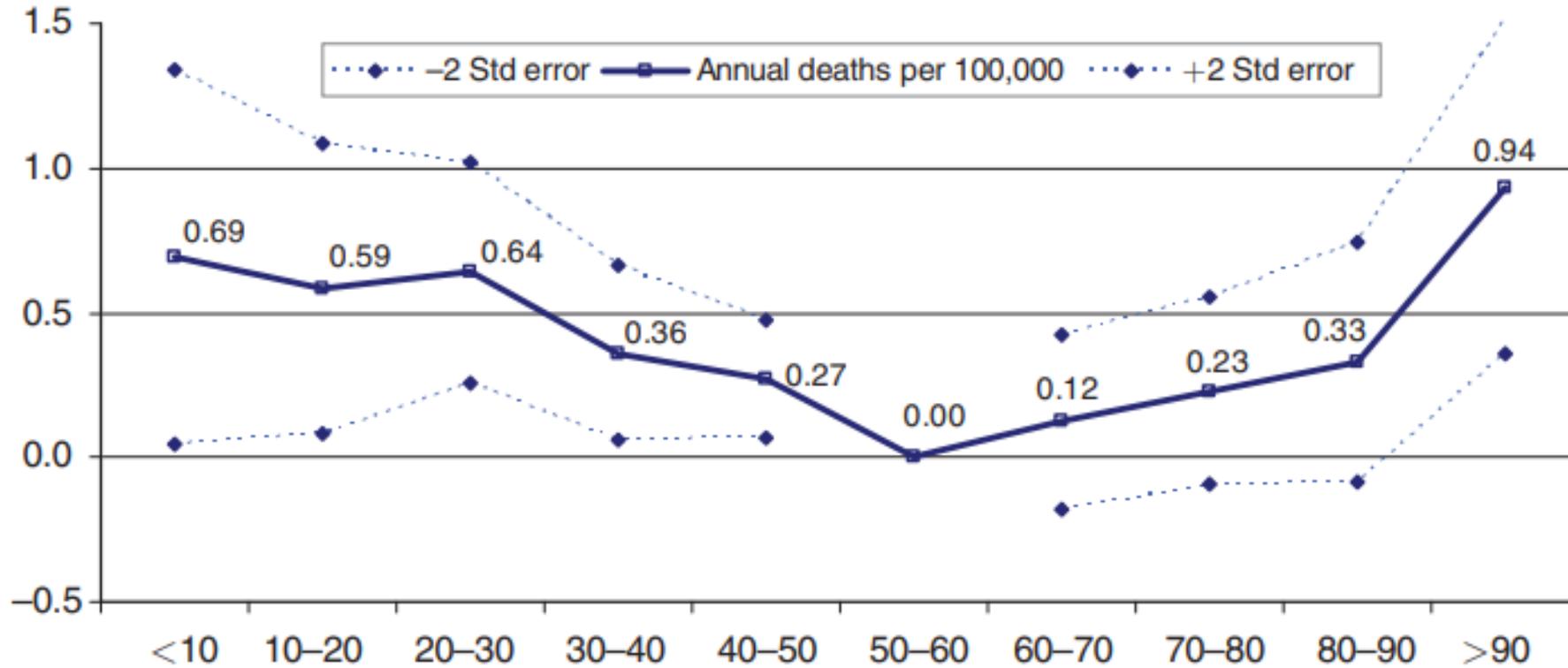
Introduction

Background: climate change and health risk?



Source: CDC Climate Effects on Health

Background: temperatures and mortality- US

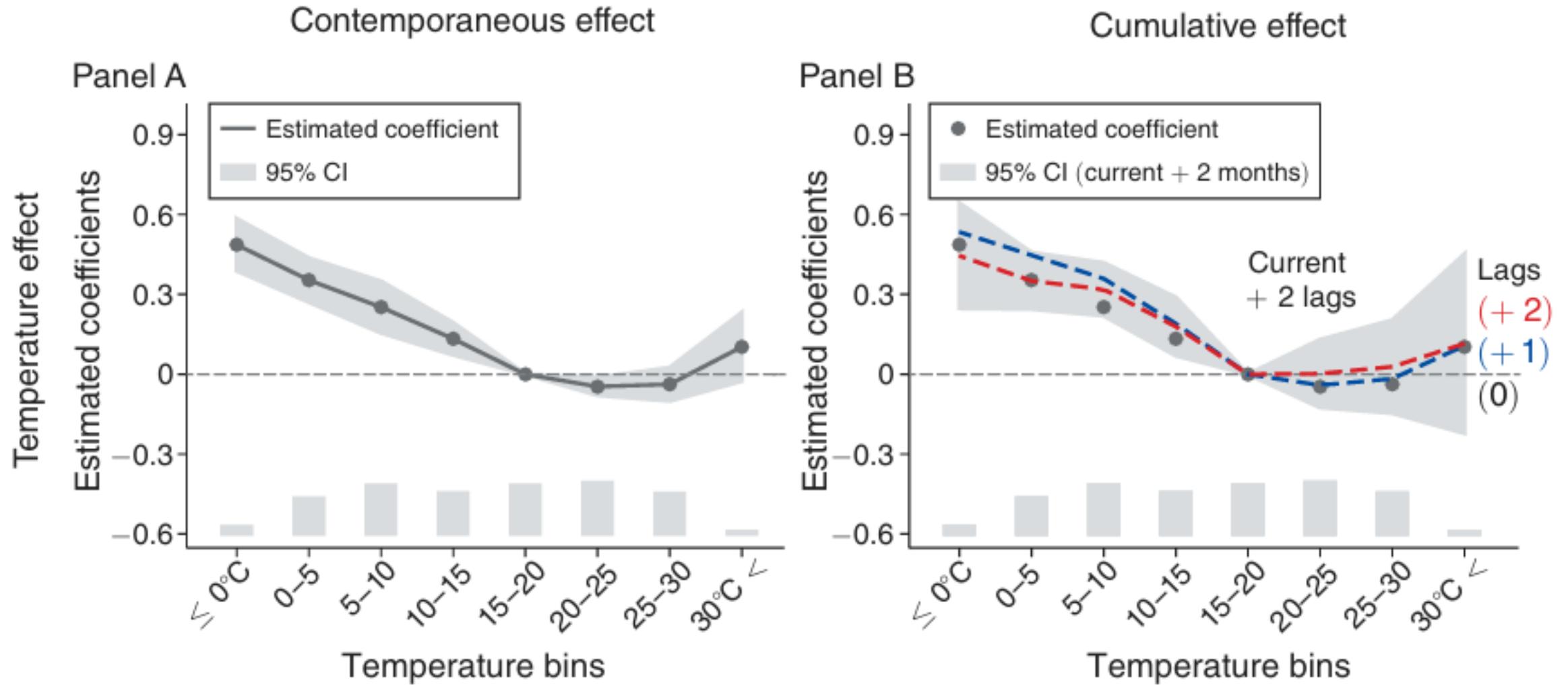


Estimated impact of a day in 9 daily mean temperature (F) bins on annual mortality rate, relative to a day in the 50°-60° F bin

FIGURE 2. ESTIMATED RELATIONSHIP BETWEEN ANNUAL AGE-ADJUSTED MORTALITY RATE PER 100,000 AND AVERAGE DAILY TEMPERATURE

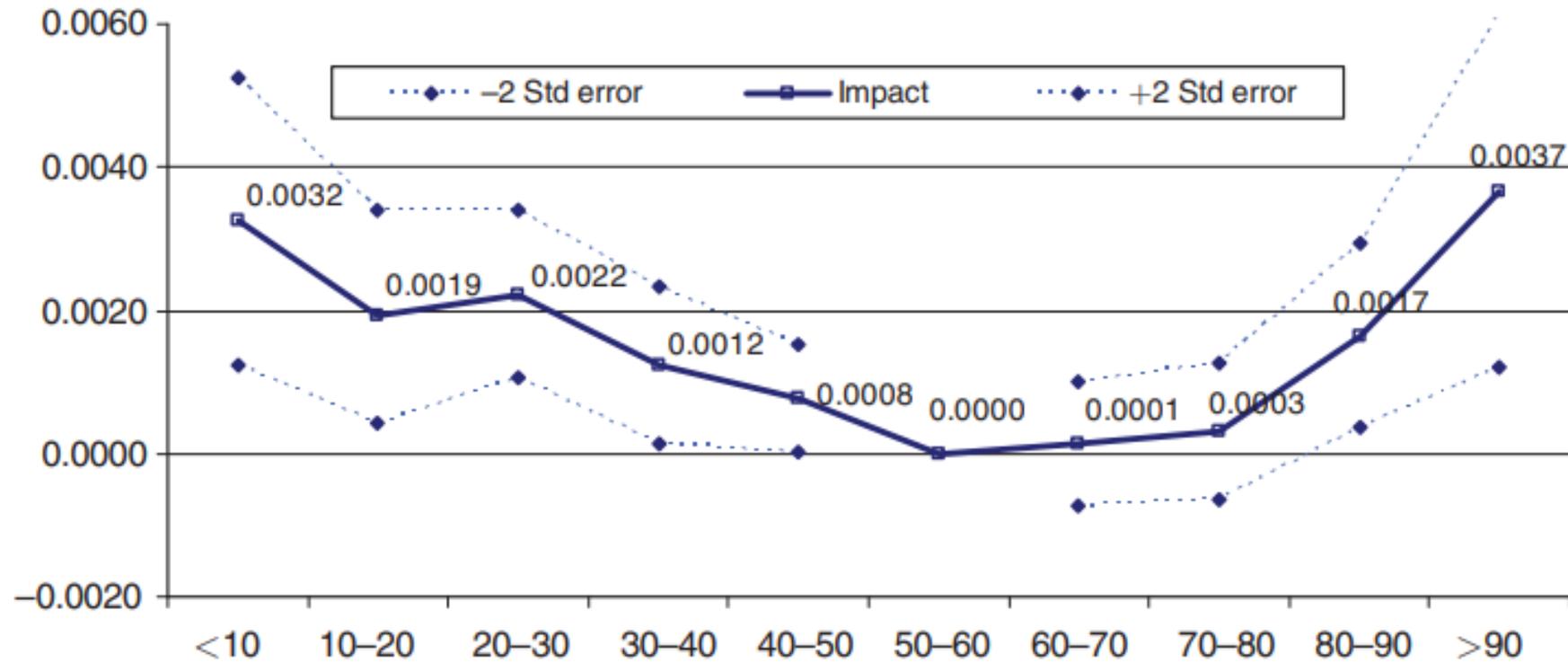
Source: Deschênes and Greenstone (2011), *AEJ: Applied Economics*

Background: temperatures and mortality- JP



Source: He and Tanaka (2023), *AEJ: Applied Economics*

Background: temperatures and residential energy consumption- US

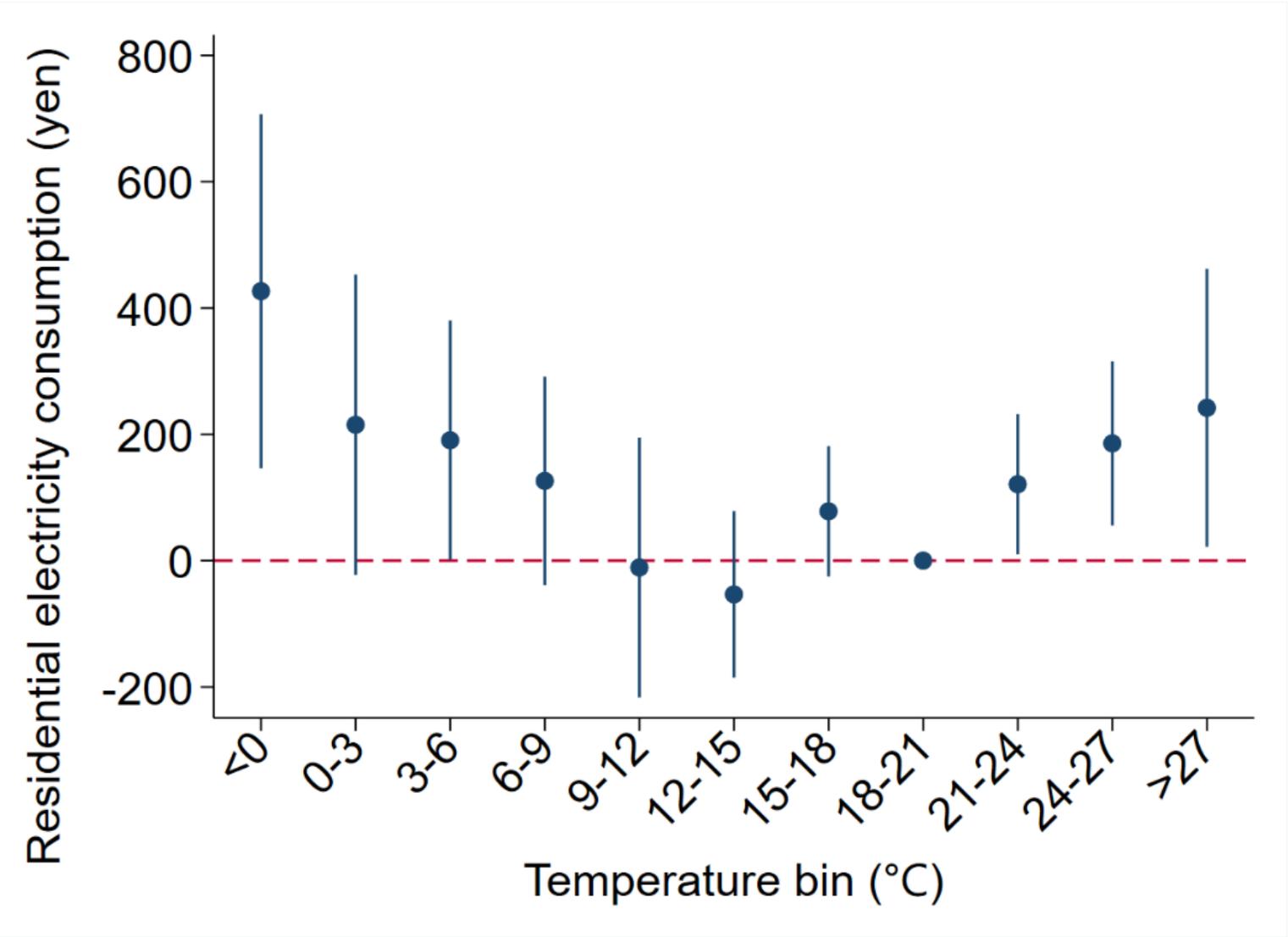


Estimated impact of a day in 9 daily mean temperature (F) bins on log annual residential energy consumption, relative to a day in the 50°-60° F Bin

FIGURE 3. ESTIMATED RELATIONSHIP BETWEEN LOG RESIDENTIAL ENERGY CONSUMPTION AND AVERAGE DAILY TEMPERATURE

Source: Deschênes and Greenstone (2011), *AEJ: Applied Economics*

Background: temperatures and residential energy consumption- JP



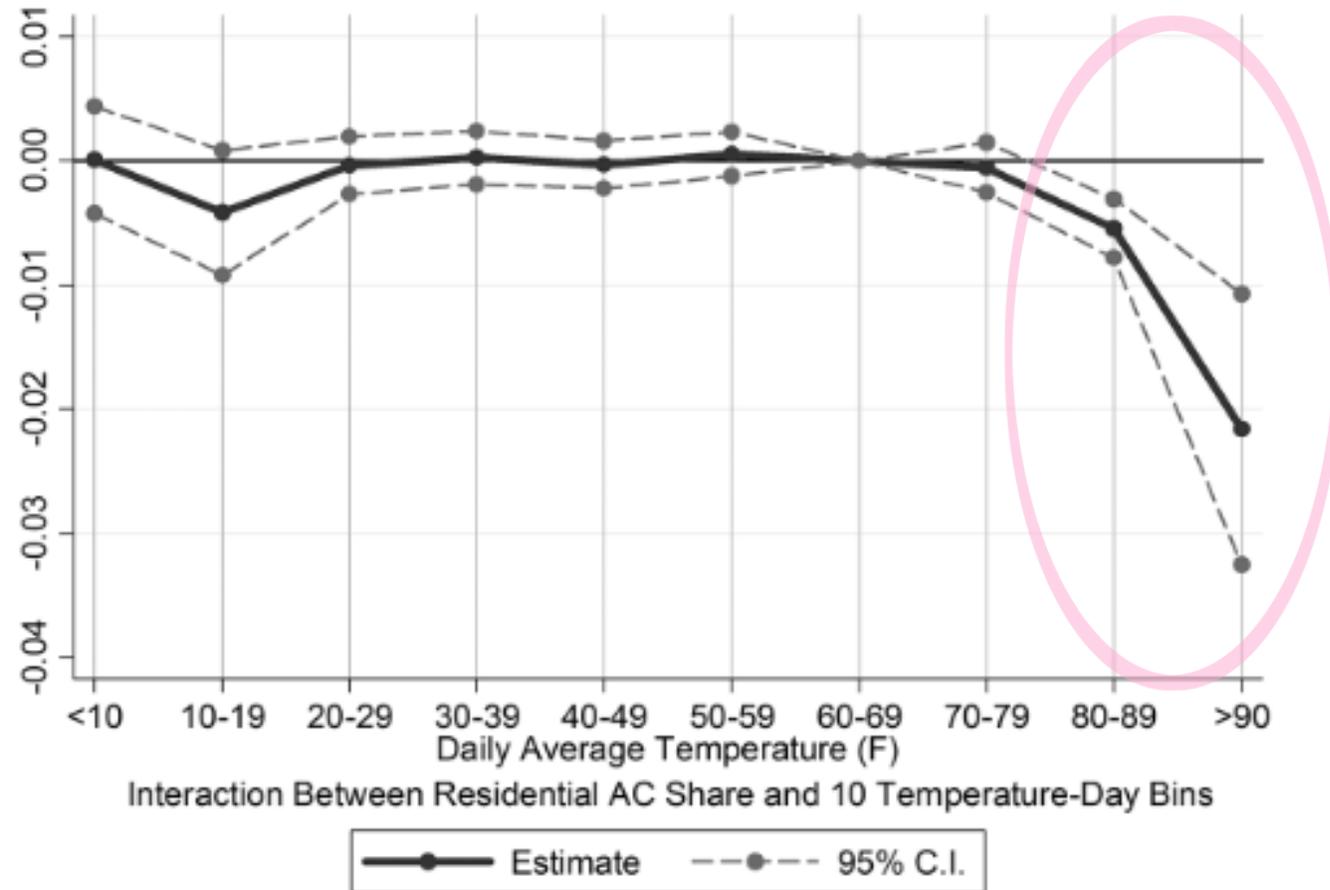
Source: Ko (2024), AGI research report

Background: temperatures affect health

- Adverse health outcomes have increased with the rise in extreme temperatures caused by climate change.
- According to the 2023 WHO fact sheets, health costs from temperature-related impacts are projected to reach US\$2-4 billion annually by 2030.
- These impacts include acute conditions like hypothermia and hyperthermia, as well as chronic illnesses such as respiratory and cardiovascular diseases.
- Existing literature highlights a U-shaped relationship between temperatures and health risks—e.g., both extreme cold and heat increase mortality rates (Heal and Park 2016, *REEP*).

Background: self-protection is available...

- Home climate control devices, such as air conditioning, serve as a form of household self-protection against extreme temperatures (Barreca et al. 2016, *JPE*).



Background: energy cost also matters

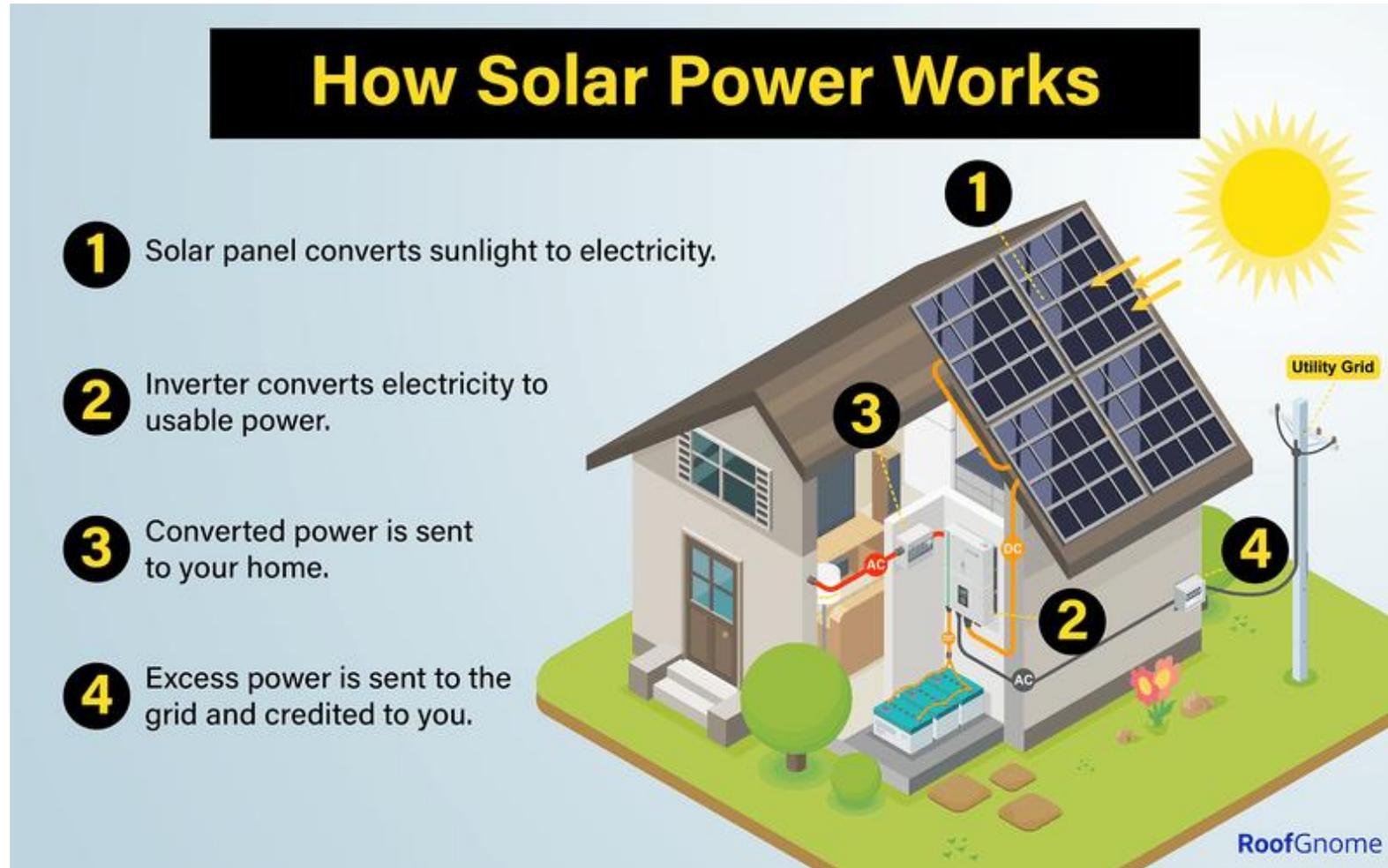
- However, their reliance on energy makes them vulnerable to rising energy costs.
- With global energy prices escalating due to recent inflation and geopolitical instability, insufficient indoor temperature control can worsen health outcomes.
- Recent studies confirm that higher energy prices are linked to increased mortality rates (Neidell et al. 2021, *J. Health Econ.*; Chirakijja et al. 2024, *Econ. J.*).
- These findings suggest that energy affordability plays a key role in mitigating health risks associated with temperature extremes.

Research objective

- This research investigates self-sufficient renewable energy technologies as a potential solution to mitigate the health risks under the pressure of high energy prices.
 - Specifically, we explore the extent to which residential solar photovoltaics (PVs) can reduce the health risks.
 - Using Japan's prefecture-month-level mortality data from 2009 to 2014, we evaluate our hypotheses within the context of the 2011 Great East Japan Earthquake, which triggered a sharp increase of electricity prices due to a shift away from nuclear power.

Why solar PVs?

- Solar PVs convert solar energy into power for household use as electricity or heat, lowering energy expenses and enabling more flexible energy use.



Source: RoofGnome (2023)

Comparison to existing studies

Study	Focus	Contribution	Difference from this study
Neidell et al. (2021), <i>J. Health Econ.</i>	Unintended health effects of halting nuclear power after Fukushima nuclear accident	Higher electricity prices increases the temperature impact on mortality	Shows how increased access to renewable energy (solar PVs) can reduce mortality . Focus shifts from systemic shock to adaptation .
He and Tanaka (2023), <i>AEJ: Applied Economics</i>	Mortality effects of energy-saving behavior post-Fukushima nuclear accident	Reduced electricity use during extreme temperatures increased mortality	Shows how self-supply through PVs can alleviate dependence on grid energy , reducing mortality risks, especially for vulnerable groups.
Rivera et al. (2024), <i>JEEM</i>	Health benefits of solar power in Chile (mainly via air quality improvement)	Solar power reduces pollution and improves respiratory health	Shifts from pollution mitigation to temperature-related mortality adaptation .

Summary of findings

- Our findings highlight that residential solar PV installations significantly mitigate the negative health impacts of extreme temperatures, especially for individuals aged 65 and older.
- These results emphasize the crucial role of renewable energy technologies in improving resilience to both extreme temperature events and fluctuations in energy prices.
- By shifting the focus from renewable energy's environmental benefits, such as CO2 reduction, to the energy-health nexus, this study emphasizes the public health implications of sustainable energy adoption.

Empirical Methodology

Empirical methodology

- The decision to install residential solar PV systems is likely endogenous to mortality outcomes due to omitted variable bias.
- For example, households adopting solar PVs may also engage in other energy-saving behaviors, such as improving home insulation or using energy-efficient appliances, which independently reduce the risk of temperature-related mortality. These unobserved characteristics, such as household attitudes toward sustainability, financial resources, or climate adaptation strategies, can influence both solar PV adoption and mortality outcomes.
- Given these concerns, a simple regression analysis would yield biased estimates. To address this, this study uses an instrumental variable (IV) approach with a two-stage least squares (2SLS) model.

Estimated equation

$$Y_{itm} = \sum_{n=1}^N \alpha_n Temp_{itm} + \sum_{n=1}^N \beta_n Temp_{itm} \times SolarPV_{itQ(m)} + \gamma_1 SolarPV_{itQ(m)} + \mathbf{Z}_{itm} \delta + \theta_{im} + \lambda_{it} + \nu_{mt} + \varepsilon_{itm},$$

Y_{itm} : log of mortality rate in prefecture i in month m of year t

$Temp_{itm}$: number of days where the daily mean temperature is in the n^{th} of the N bins

$SolarPV_{itQ(m)}$: solar PV installation in the most recent quarter before month m

\mathbf{Z}_{imt} : mean monthly precipitation, wind speed, and snow depth, as well as income, that are classified into ten quantile groups

θ_{im} : prefecture by month fixed effect

λ_{it} : prefecture by year fixed effect

ν_{mt} : year-by-month fixed effect

Solar PV adjustment

- If $m = 1, 2, 3$, then it refers to Q4 of year $t-1$.
- If $m = 4, 5, 6$, then it refers to Q1 of year t .
- If $m = 7, 8, 9$, then it refers to Q2 of year t .
- If $m = 10, 11, 12$, then it refers to Q3 of year t .

Month (m)	Calendar month	Correct PV data (lagged)	Used quarter	If no lag is used (misalignment)
1	January	Q4 of year $t-1$	Oct.–Dec. ($t-1$)	Would use Q1 (Jan.–Mar.) total, which includes February and March—data not yet available in January
2	February	Q4 of year $t-1$	Oct.–Dec. ($t-1$)	Would use Q1 (Jan.–Mar.) total, which includes March—data not yet available in February

IV

Instrument component	Description	Reason for validity
Global solar radiation	Past five-year average of solar radiation during summer months	<ul style="list-style-type: none">- Directly influences the financial attractiveness of solar PV installation.- Regions with higher solar radiation have greater energy output, making solar more economically viable.
Electricity prices (lagged)	Electricity prices from the same month in the previous year	<ul style="list-style-type: none">- Electricity prices vary seasonally, influencing households' incentives to adopt solar PV.- Lagging avoids contemporaneous effects on mortality, capturing investment incentives.
Interaction of both variables	Interaction between global solar radiation and lagged electricity prices	<ul style="list-style-type: none">- The interaction between global solar radiation and lagged electricity prices creates a wealth-related proxy, reflecting both the economic potential (solar energy output) and financial incentives (electricity savings) that influence solar PV adoption decisions.

Data

Mortality, household characteristic and electricity price data

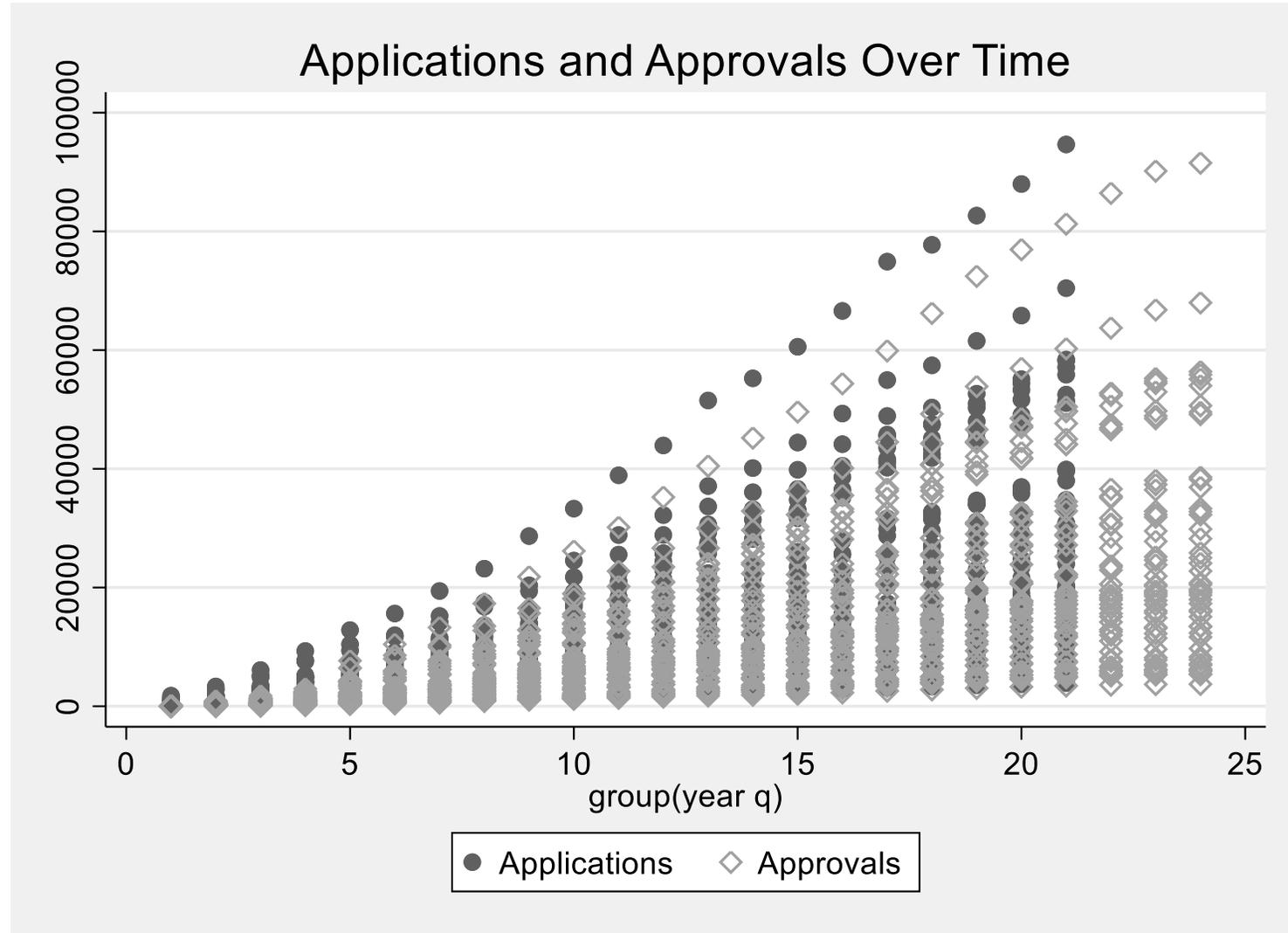
- The monthly mortality data and household characteristics, such as income, used in this study are obtained from He and Tanaka (2023).
- Following He and Tanaka (2023), we exclude three prefectures—Iwate, Miyagi, and Fukushima—from our primary analysis, as these regions were directly affected by the earthquake and tsunami, making them less comparable to other prefectures.
- The monthly marginal electricity price data is from Retail Price Survey (Trend Survey) from Statistics Bureau, Ministry of Internal Affairs and Communications.
- Since the government uses 441 kWh as the standard monthly electricity consumption for households in its statistics and modeling, we calculate the average electricity price based on this standard and use it in the analysis.

Residential solar PV installation data

- This study utilizes data on quarterly residential solar PV installations from the Japan Photovoltaic Energy Association (JPEA), which oversaw a national subsidy program for solar PV systems.
- Running from January 2009 to March 2014, the program provided financial support for households installing solar PVs. The subsidy was available to households across all prefectures.
- To qualify for the subsidy, households had to apply before installation, and over 96% of applications were approved, leading to successful installations.
- The number of approved applications is used by the government as the official count of residential solar PV installations, suggesting that the subsidy program covered nearly all residential solar PV installations during this period.

Comparison of data sources and focus with previous study

Aspect	Kiso et al. (2022), <i>JEEM</i>	This study
Data source	Application data (focused on timing of adaptation)	Approval data (focused on actual installations)
Focus of study	Timing of adaptation behaviors	Impact of solar PV installation on temperature-mortality relationship



Weather data

- The weather data utilized in this study is sourced from Agro–Meteorological Grid Square Data, NARO.
- They provide 14 types of daily meteorological weather data by 1km square (third–order grid unit) covering the entirety of Japan.
- Consistent with previous studies, our analysis focuses on four key weather variables: daily mean temperature, precipitation, wind speed, and snow depth. Additionally, global solar radiation is utilized as an IV in our analysis.
- To harmonize the grid–level data with prefecture–level data, we leverage a list of mesh codes by city provided by the Statistics Bureau of Japan.

Table 1—Summary statistics

	Obs.	Mean	SD	Min	Max
Age-adjusted mortality rate (per 100,000)	3,168	83.7	10.3	60.6	125.7
Mortality rate age 0–19 (per 100,000)	3,168	2.1	0.9	0	8.4
Mortality rate age 20–64 (per 100,000)	3,168	11.7	2.1	5	21.7
Mortality rate age over 65 (per 100,000)	3,168	318.2	38.4	230.3	449.8
<15 °C (days)	3,168	16.1	13.8	0	31
15–30 °C (days)	3,168	14.8	13.7	0	31
>30 °C (days)	3,168	0.1	0.6	0	13.2
Cumulative residential solar PV installations	3,168	11,837.8	14,154.1	3	91,530

Notes: The unit of mortality rate and temperature bins are a prefecture in each month between 2009 and 2014, while the unit of observation for solar PV installation is a prefecture in each quarter over same timeframe.

An age-adjusted mortality rate is constructed by weighting each age group's mortality rate by its respective population share.

From a statistical perspective, we categorize temperature into three bins: <15° C, 15–30° C, and >30° C to reduce model complexity and minimize potential overfitting. This approach simplifies the estimation while retaining the key variations in temperature exposure.

Estimation Results

Nonlinear temperature effects on mortality

	(1) age-adjusted
<15°C	0.0016*** (0.0004)
>30°C	0.0045*** (0.0014)
Obs.	3,168
Num. of prefectures	44
Control var.	Yes
F statistic	12.99
Prob > F	0.0000
R-squared	0.9705

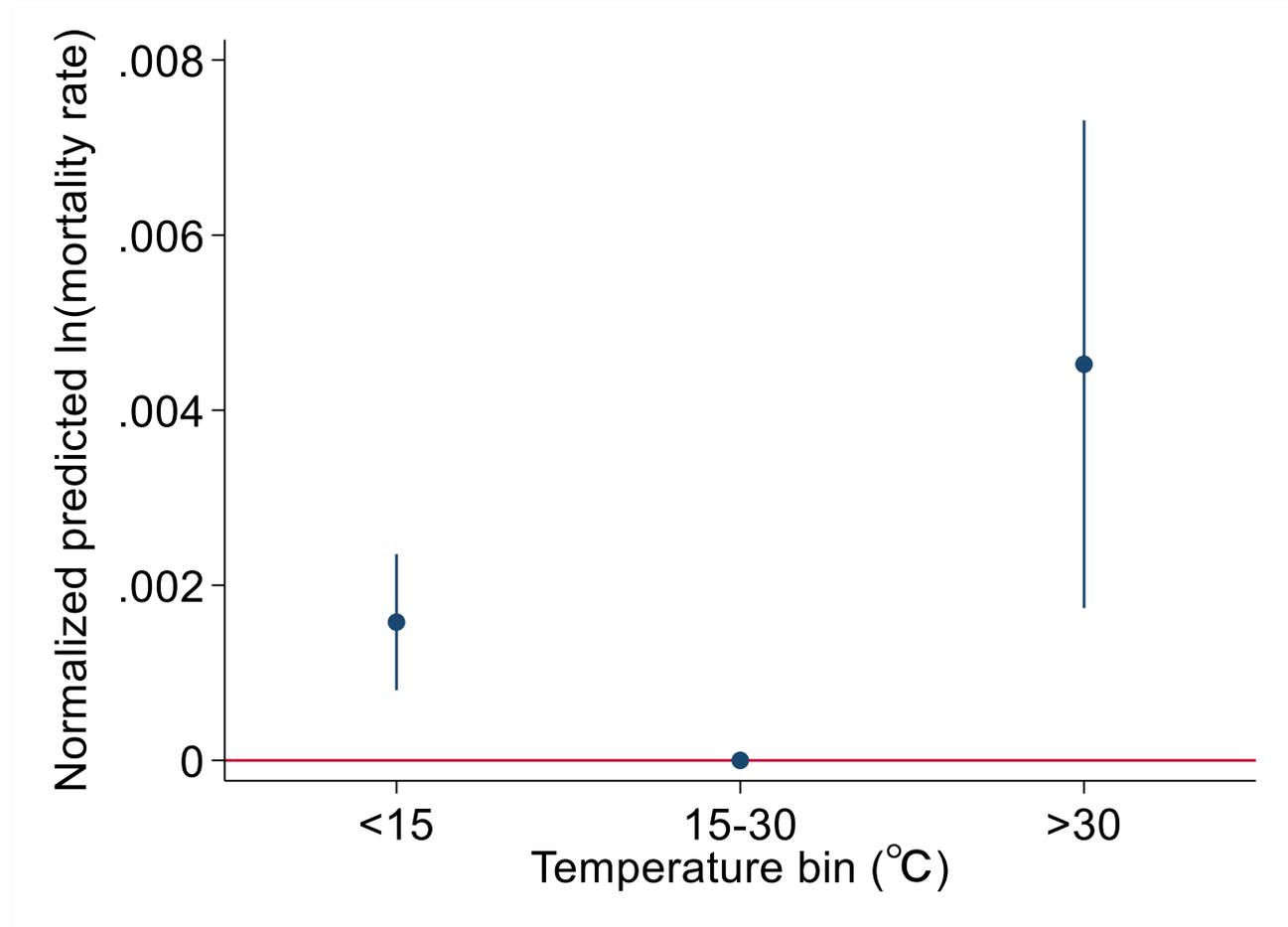


Figure 2: Relationship between temperature and mortality rate

Notes: ***, **, and * denote 1 percent, 5 percent, and 10 percent significant level, respectively. All regressions are weighted by population. Standard errors clustered at the prefecture level are reported in parentheses.

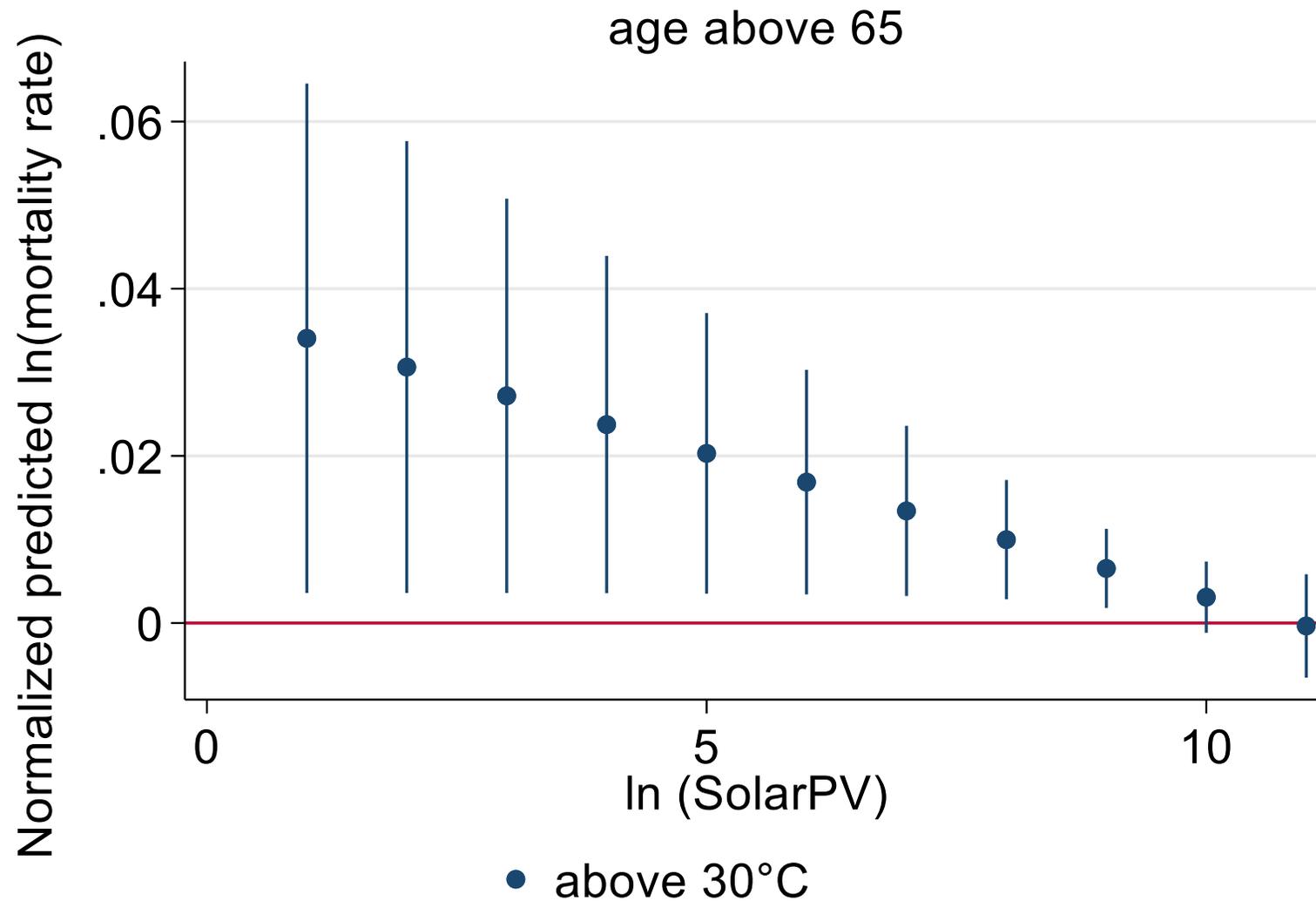
Nonlinear temperature effects on mortality: different age categories

	(1) 0–19	(2) 20–64	(3) above 65
<15°C	-0.0042 (0.0066)	0.0011 (0.0014)	0.0017*** (0.0004)
>30°C	-0.0037 (0.0116)	0.0055*** (0.0015)	0.0045*** (0.0016)
Obs.	3,115	3,168	3,168
Num. of prefectures	44	44	44
Control var.	Yes	Yes	Yes
F statistic	0.25	6.89	15.13
Prob > F	0.7799	0.0025	0.0000
R-squared	0.3127	0.8266	0.9675

The impact of residential solar PV installation on the temperature-mortality relationship

	(1) age-adjusted	(2) 0–19	(3) 20–64	(4) above 65
<15°C	-0.0038 (0.0054)	-0.0107 (0.0243)	0.0063 (0.0095)	-0.0001 (0.0042)
<15°C × solar PV	0.0008 (0.0006)	0.0007 (0.0032)	-0.0006 (0.0010)	0.0002 (0.0005)
>30°C	0.0544* (0.0270)	-0.0880 (0.1399)	-0.0072 (0.0481)	0.0375** (0.0168)
>30°C × solar PV	-0.0050* (0.0028)	0.0087 (0.0152)	0.0013 (0.0048)	-0.0034* (0.0017)
Obs.	3,036	2,985	3,036	3,036
Num. of prefectures	44	44	44	44
Control var.	Yes	Yes	Yes	Yes
F statistic	5.95	0.31	3.33	4.76
Prob > F	0.0003	0.9044	0.0125	0.0015
First stage SW F >10	Yes	Yes	Yes	Yes

The impact of residential solar PV installation on the temperature-mortality relationship: graphical



Placebo Test

Different causes of death: cardiovascular vs accident

	(1) above 65 CVD	(2) above 65 Accident	(3) age-adj. CVD	(4) age-adj. Accident
<15°C	-0.0054 (0.0060)	0.0039 (0.0176)	-0.0038 (0.0054)	0.0088 (0.0168)
<15°C × solar PV	0.0010 (0.0007)	-0.0005 (0.0020)	0.0008 (0.0006)	-0.0010 (0.0019)
>30°C	0.0707** (0.0307)	-0.0268 (0.0557)	0.0544* (0.0270)	0.0189 (0.0460)
>30°C × solar PV	-0.0068** (0.0031)	0.0013 (0.0057)	-0.0050* (0.0028)	-0.0030 (0.0047)
Obs.	3,036	3,036	3,036	3,036
Num. of prefectures	44	44	44	44
Control var.	Yes	Yes	Yes	Yes
F statistic	6.00	2.03	5.95	2.67
Prob > F	0.0003	0.0928	0.0003	0.0344
First stage SW F >10	Yes	Yes	Yes	Yes

Heterogeneity Test

Different climate: warmer vs colder

	(1) above 65 Warmer	(2) above 65 Colder	(3) age-adj. Warmer	(4) age-adj. Colder
<15°C	-0.0129 (0.0142)	0.0055 (0.0036)	-0.0086 (0.0119)	0.0040 (0.0030)
<15°C × solar PV	0.0015 (0.0015)	-0.0007 (0.0005)	0.0011 (0.0012)	-0.0005 (0.0004)
>30°C	0.0737*** (0.0225)	0.1053 (0.0642)	0.0634*** (0.0270)	0.1064 (0.0626)
>30°C × solar PV	-0.0070** (0.0025)	-0.0100 (0.0069)	-0.0060** (0.0022)	-0.0102 (0.0068)
Obs.	1,518	1,518	1,518	1,518
Num. of prefectures	22	22	22	22
Control var.	Yes	Yes	Yes	Yes
F statistic	17.52	1.50	13.62	2.07
Prob > F	0.0000	0.2309	0.0000	0.1093
First stage SW F >10	Yes	Yes	Yes	Yes

Different energy saving rate: higher vs lower

	(1) above 65 Higher	(2) above 65 Lower	(3) age-adj. Higher	(4) age-adj. Lower
<15°C	-0.0136 (0.0105)	-0.0113 (0.0773)	-0.0115 (0.0093)	0.0006 (0.0219)
<15°C × solar PV	0.0017 (0.0011)	0.0019 (0.0113)	0.0014 (0.0010)	0.0001 (0.0032)
>30°C	0.0805*** (0.0244)	0.5394 (2.4546)	0.0700*** (0.0209)	0.1777 (0.6744)
>30°C × solar PV	-0.0079*** (0.0025)	-0.0512 (0.2347)	-0.0069*** (0.0021)	-0.0167 (0.0644)
Obs.	1,449	1,587	1,449	1,587
Num. of prefectures	21	23	21	23
Control var.	Yes	Yes	Yes	Yes
F statistic	6.54	0.06	5.56	1.15
Prob > F	0.0009	0.9976	0.0023	0.3640
First stage SW F > 10	Yes	No	Yes	No

Concluding Remarks

- This study investigates the impact of residential solar PV installations on the relationship between temperature extremes and mortality.
- We find that solar PV installations have a significant role in mitigating the adverse effects of high temperatures on mortality, particularly for individuals aged 65 and above.
- Policymakers could consider promoting solar energy adoption, especially in regions with aging populations or those vulnerable to temperature extremes. This could be a key strategy in mitigating climate-related health risks, particularly in improving the well-being of elderly individuals and those with pre-existing health conditions.

Next steps: exploring mechanisms & inequality in impact

- How do solar PVs reduce temperature-related mortality?
 - Key mechanism: energy self-sufficiency → enables air conditioner use during extreme heat, etc.
- What drives differences in effectiveness?
 - Income levels → who can afford to install and benefit from solar PVs?
 - Geographic conditions → areas with more sunlight gain more from PV systems
 - Policy context → regions with supportive incentives may see stronger adoption and effects
- Goal?
 - Identify barriers and tailor policies to ensure solar PV benefits are equitably distributed—strengthening climate resilience for all.

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Thank you for your time!

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