Global and Local Damages from Climate Change

Michael Greenstone (University of Chicago)

EPIC ENERGY POLICY INSTITUTE AT THE UNIVERSITY OF CHICAGO

Climate Impact Lab

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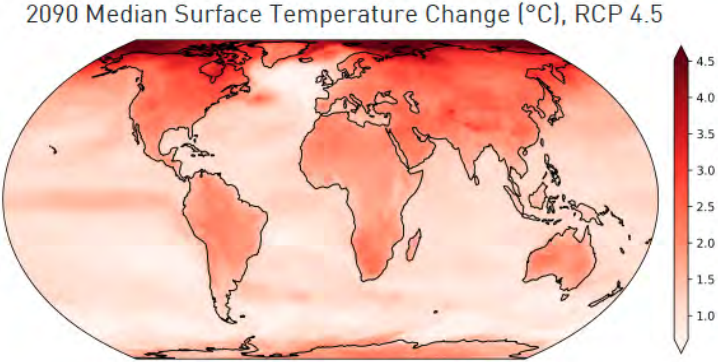
Climate change will have large effects on global temperatures



Climate change will have many impacts on human wellbeing

Extreme Heat

Climate change will have many impacts on human wellbeing

Extreme Heat

More Powerful Storms

Climate change will have many impacts on human wellbeing

Extreme Heat

More Powerful Storms

More Frequent Wildfires

Climate change is a **global** challenge, but its impacts are felt **locally**

Source: Associated Press

Climate change is a **global** challenge, but its impacts are felt **locally**

Key Takeaways

Advances in economics and climate science allow for quantification of the global- and local-level impacts of climate change.

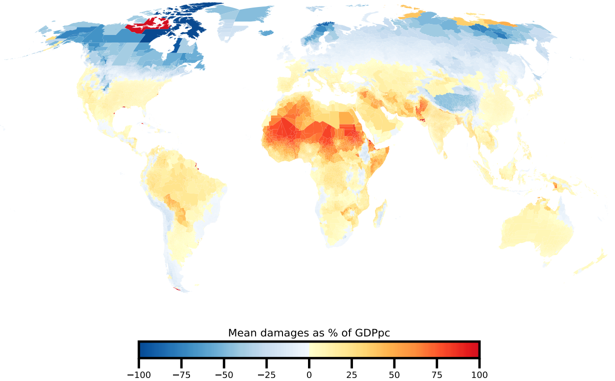
Damages are larger and more heterogeneous than previously thought

- 2099 damages are estimated to be equivalent to 6.4% of global GDP under high emissions
- For low income countries, damages are estimated to be 12% of GDP

Key Takeaways

Costs are especially concentrated in today's poor and hot places

Combined Damages in 2099



Scenario: RCP8.5 & SSP3

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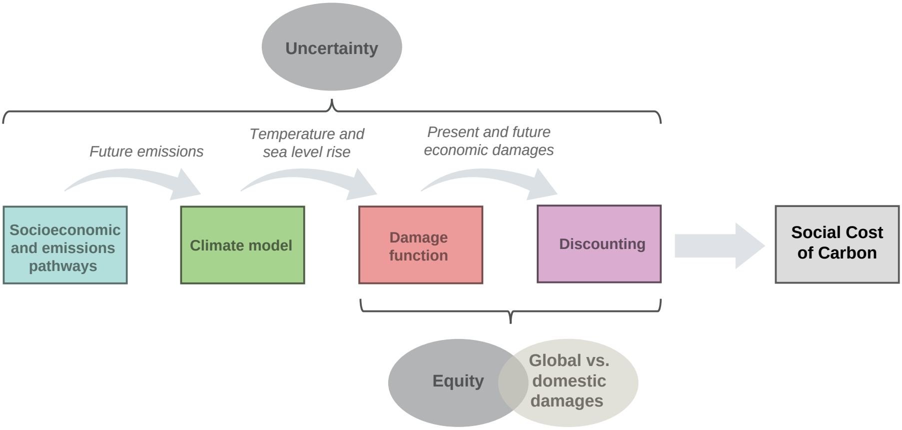
The Social Cost of Carbon

The Social Cost of Carbon (SCC) - the monetary value of the damages imposed by the release of one additional ton of carbon dioxide.

For every climate change mitigation policy, the SCC is central to determining whether it is cost-effective.

The SCC enables analysis of policy tradeoffs involving climate change mitigation.

"Ingredients" for estimating the SCC



Carleton & Greenstone (REEP, *2022*)

Updating the Social Cost of Carbon

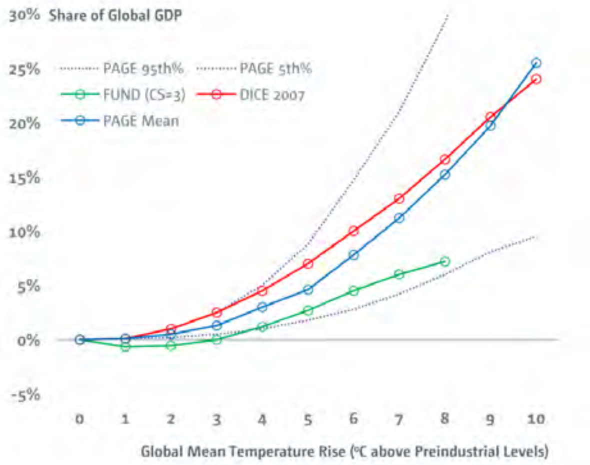
The SCC is important summary measure of climate damages

- New CIL SCC estimates are ~4 times larger than previously estimated.
- These estimates suggest that current yearly emissions correspond to ~$7 Trillion damages (~7% of current global GDP)

Outline

1. Approach to Estimating Climate Change Impacts: 1990-2020
2. Approach to Estimating Climate Change Impacts: After 2020
   - Mortality
   - Electricity
   - Labor
   - Characterization of Uncertainty
3. Partial (Aggregate) Climate Damages
   - Climate Damages Year by Year
   - Social Cost of Carbon

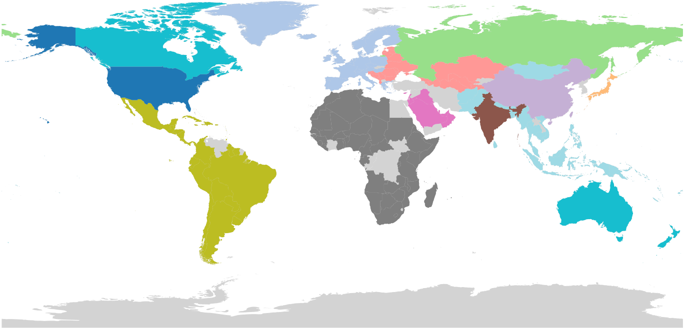
Original IAM damage assessments



Source: Interagency Working Group on SCC, 2010

Original IAM damage assessments

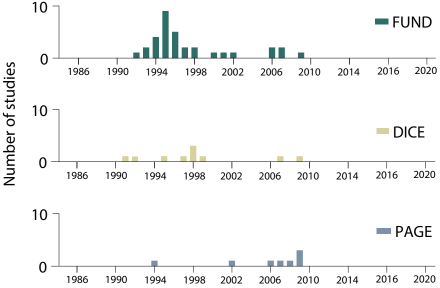
RICE model includes 12 regions: US, EU, Japan, Russia, Eurasia, China, India, Middle East, Africa, Latin America, other higher-income, and other non-OECD Asia (Nordhaus 2010)

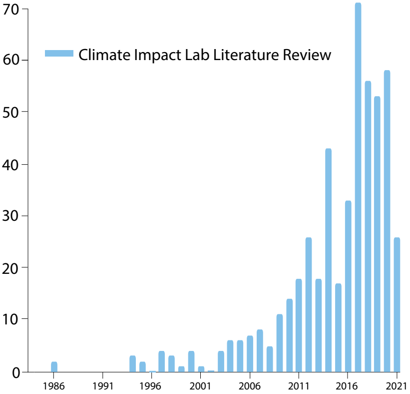


Original IAM damage assessments

"[M]uch of the research on which [the SCC models] are based is dated...damage formulations do not in many cases reflect recent advances in the scientific literature."

–National Academies of Sciences, Engineering, and Medicine (2017)





Empirical publications informing these models

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CIL Guiding Principles

Global climate damage calculations should...

$\longrightarrow$ be based on best-available **empirical evidence**

$\longrightarrow$ be based on best-available **climate models**

$\longrightarrow$ be **globally representative**

$\longrightarrow$ account for **adaptation** and **its costs**

$\longrightarrow$ value **uncertainty** and **unequal impacts**

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For this purpose, the Climate Impact Lab has developed the **Data-driven Spatial Climate Impact Model (DSCIM)**.

CIL Produces Hyper-local Estimates of Damages

∼25,000 impact regions capture subnational inequality of damages

Modular damage analysis

Mortality — heat and cold deaths (Carleton et al, *QJE 2022*)

All-cause mortality ($<$5) All-cause mortality ($>$64)

All-cause mortality (5-64)

Agriculture — crop yields (Hultgren et al, *in review*)

Maize Wheat Rice

Soybean Sorghum Cassava

Energy — energy and electricity demand (Rode et al, *Nature 2021*)

Electricity consumption Other fuels consumption

Labor — labor supply & disamenity (Rode et al, *in review*)

High risk labor Low risk labor

Coastal — sea level rise and storm damages (Depsky et al, *GMD 2022*)

Sea level rise inundation SLR $\times$ tropical cyclone surge

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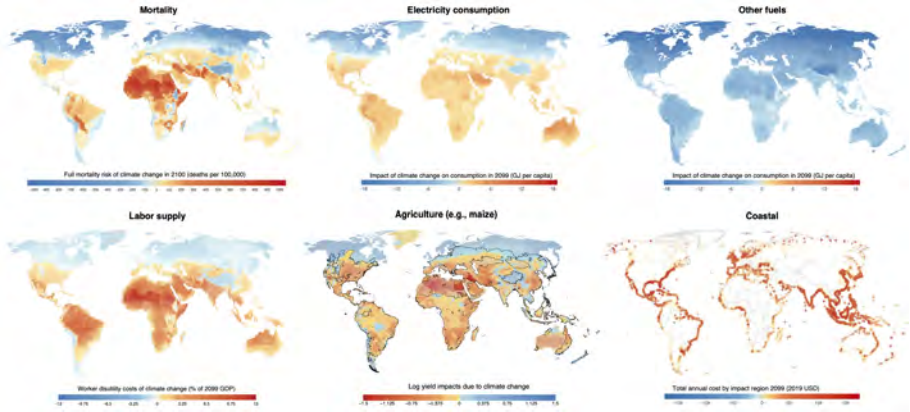
Sea level rise inundation
SLR $\times$ tropical cyclone surge

...

Integration — valuing marginal damages (Nath et al, *2022*)

Intertemporal discounting
Valuing inequality
Pricing risk

Global climate change damages across sectors: 2099



Scenario: RCP8.5 & SSP3

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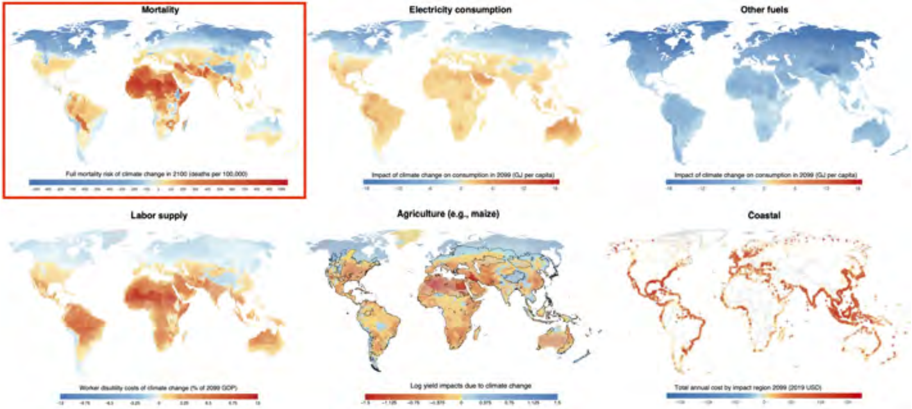

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Quantifying climate damages from mortality

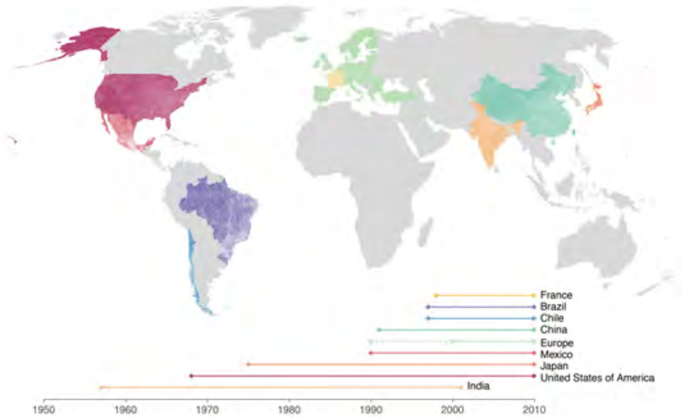
THE QUARTERLY JOURNAL OF ECONOMICS

VALUING THE GLOBAL MORTALITY CONSEQUENCES OF CLIMATE CHANGE ACCOUNTING FOR ADAPTATION COSTS AND BENEFITS*

TAMMA CARLETON
AMIR JINA
MICHAEL DELGADO
MICHAEL GREENSTONE
TREVOR HOUSER
SOLOMON HSIANG
ANDREW HULTGREN
ROBERT E. KOPP
KELLY E. MCCUSKER
ISHAN NATH
JAMES RISING
ASHWIN RODE
HEE KWON SEO
ARVID VIAENE
JIACAN YUAN
ALICE TIANBO ZHANG

Mortality data coverage

Subnational mortality records covering 55% of the global population



Age-specific annual mortality rates at ∼county level

Carleton et al. (QJE, 2022)

Estimating an impact relationship

Concept

Use random variation in short-run weather to causally identify the effect of weather realizations on sector-specific outcomes.

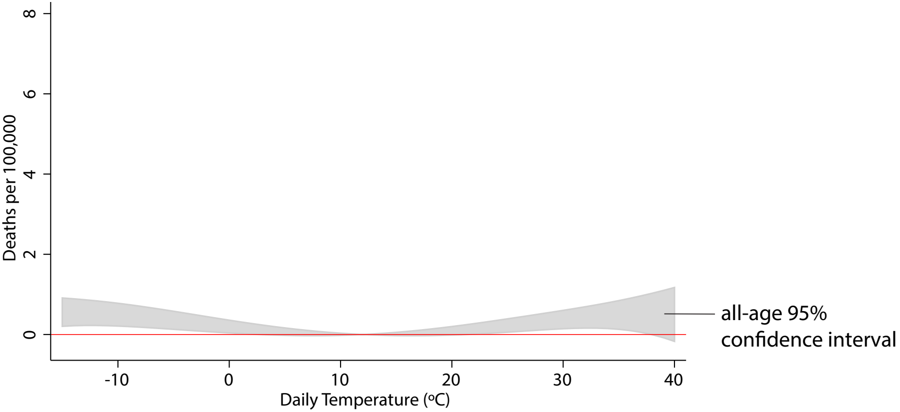
For example:

$$Mortality\_rate_{ait} = f_a(Temp_{it}) + g_{ca}(Precip_{it}) + \underbrace{\alpha_{ai} + \delta_{act}}_{\text{nonparametric location \& time controls}} + \varepsilon_{iat}$$

Mortality rates observed for **age group** a in **location** i in **country** c at **date** t.

Quantifying climate damages from mortality

Extreme heat and extreme cold impact mortality rates:



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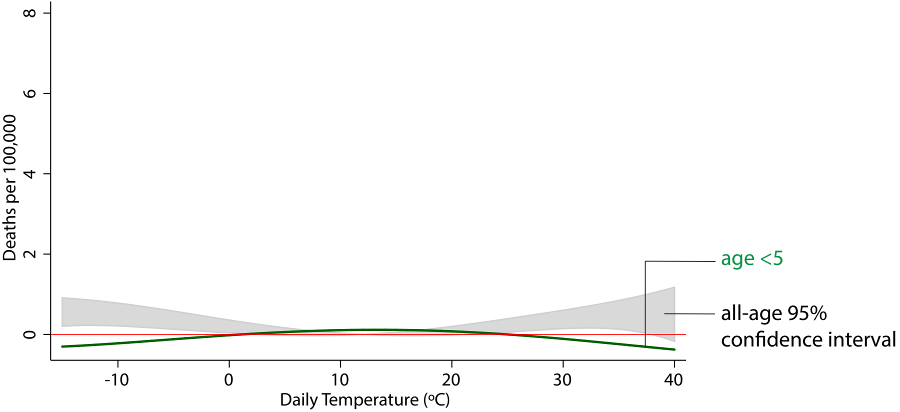

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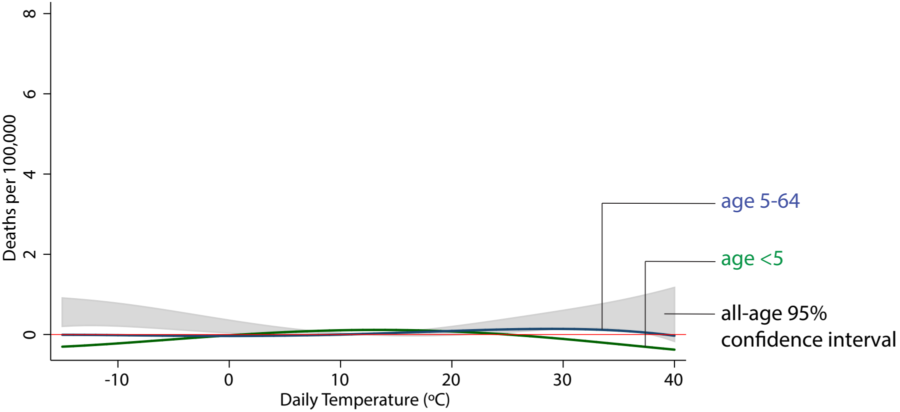

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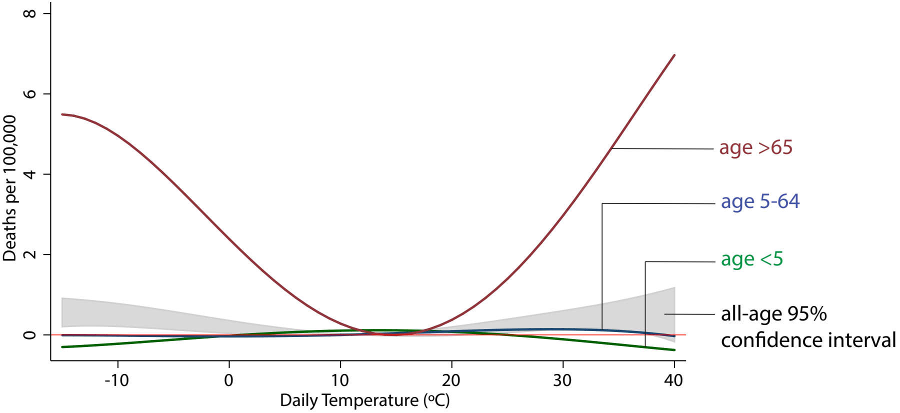


Heterogeneity in response to weather

Concept

Allow the shape of the function describing the impact relationship at a location be a function of conditions at that location.

$$Outcome_{it} = \sum_{p} \beta^{p} \, Weather_{it}^{p} \, ... \, controls$$

$$\uparrow$$

$$\beta^{p}(i) = \gamma_0^{p} + \gamma_1^{p} \, Climate_i + \gamma_2^{p} \log(GDPpc)_i + ...$$

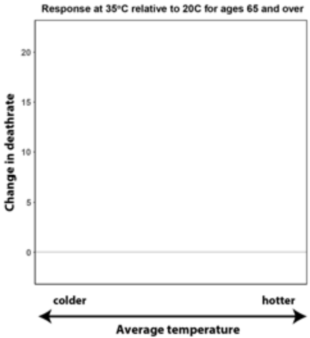
Covariates determining heterogeneity depend on sector

$\rightarrow$ $Climate_i$ = long-run avg. climate (e.g. temperature, degree days, precipitation)

$\rightarrow$ $\log(GDPpc)_i$ = average log income per capita

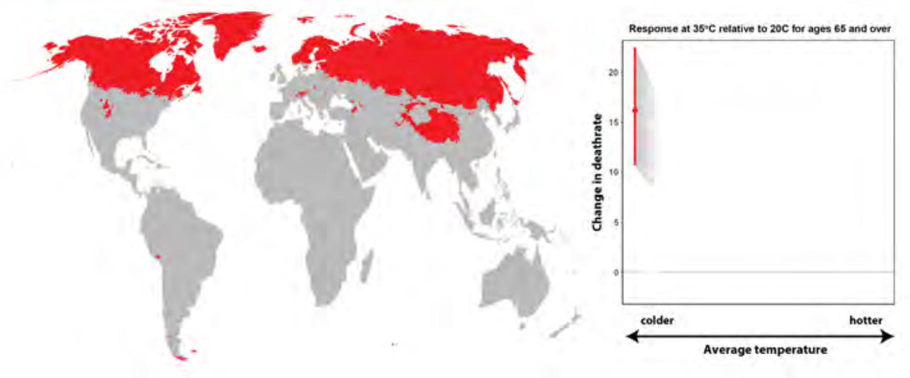
$\rightarrow$ $area\_irrigated_i$ = share of area equipped for irrigation

Mortality damages vary by climate



Effect day at 35°C relative to 20°C for ages 65 and over.
Coefficient calculated for deciles of *TMEAN* (red shaded area).

Mortality damages vary by climate



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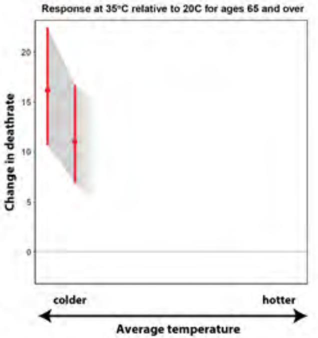

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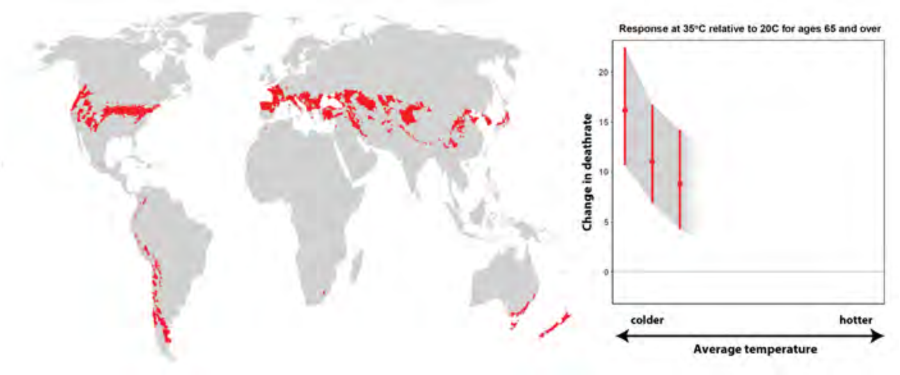

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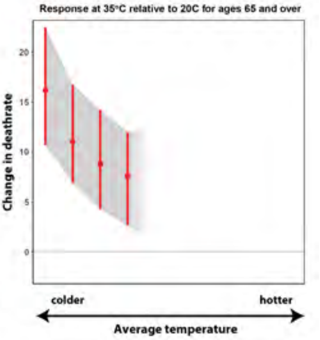

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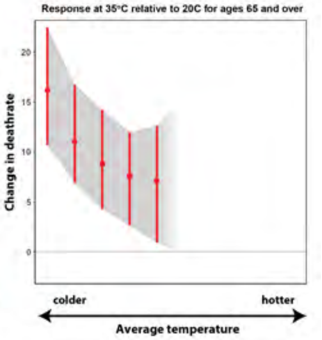

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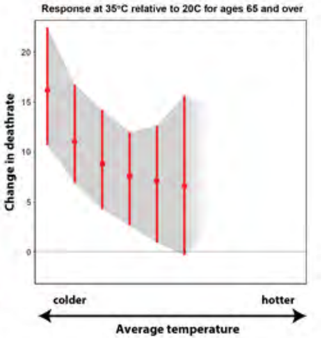

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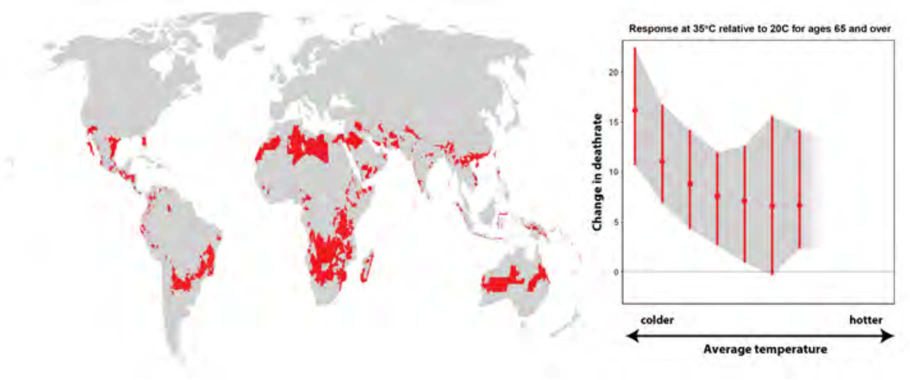

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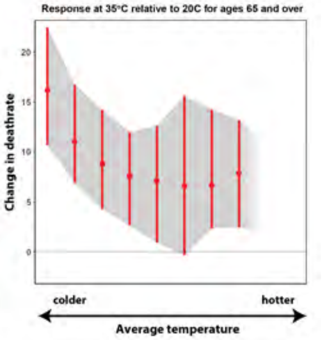

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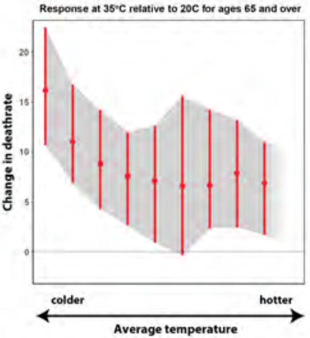

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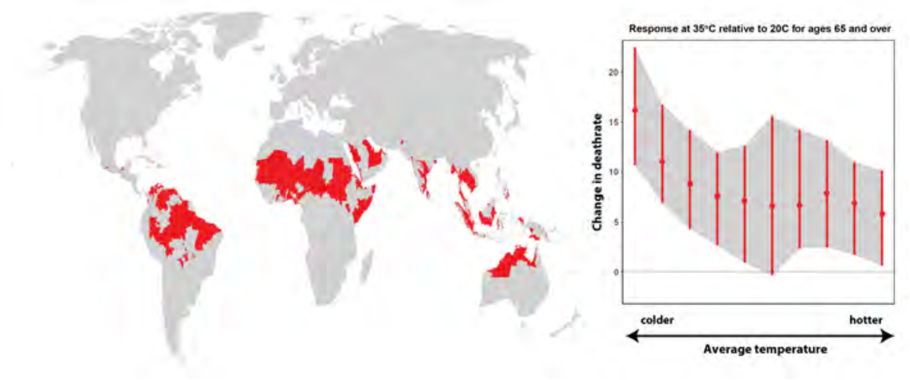

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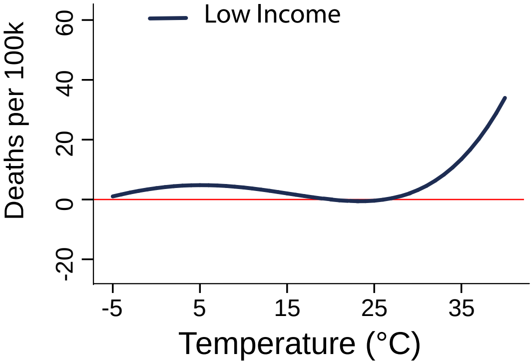
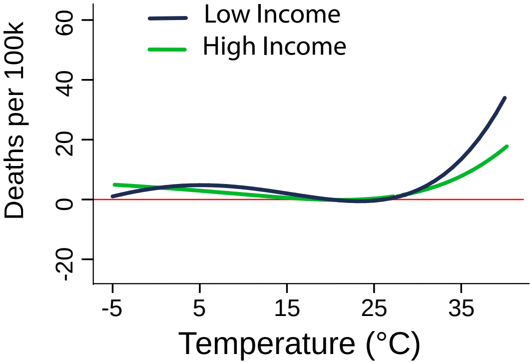
Mortality damages vary by income



Response function for 65+ age group in cold regions. Income groups split into terciles at the region level.

Mortality damages vary by income



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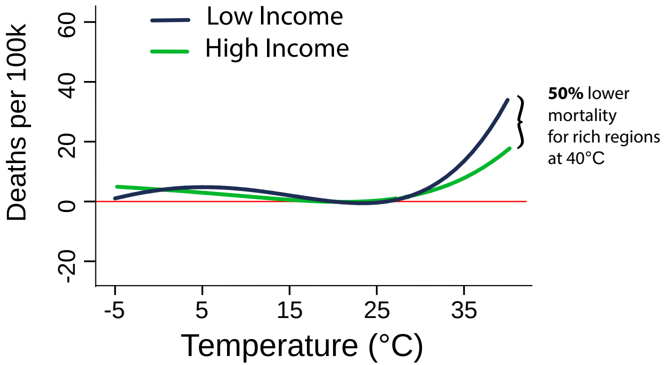


Response function for 65+ age group in cold regions. Income groups split into terciles at the region level.

How to fairly represent the global population?

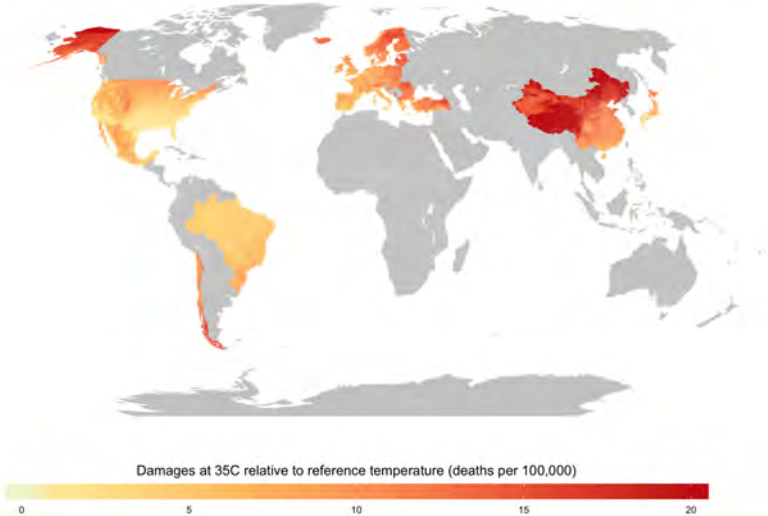
We use our estimated response surface to predict response functions for all impact regions globally.

$$\hat{\beta}^p(r) = \hat{\gamma}_0^p + \hat{\gamma}_1^p \underbrace{TMEAN_r}_{observable} + \hat{\gamma}_2^p \underbrace{\log(GDPpc)_r}_{observable} + ...$$

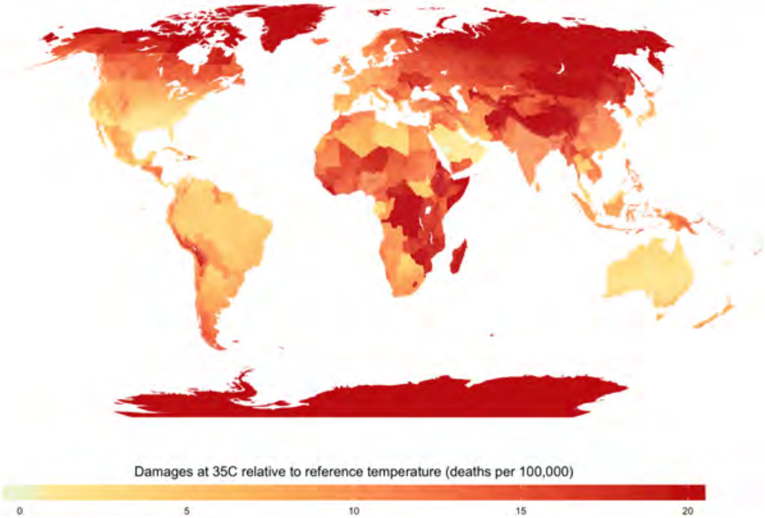
Requires we assemble data for present (and future) in each region r

- **Income & populaton:**
  - OECD $\times$ nightlights $\rightarrow$ downscale income to subnational level
  - IIASA Shared Socioeconomic Pathways (SSP) incomes to 2100
- **Weather & climate:**
  - 33 GCMs downscaled to impact region level
  - Average climate calculated as 15 year average of temperature
- **Irrigation:**
  - FAO Aquastat
  - Held fixed at present levels for all future years

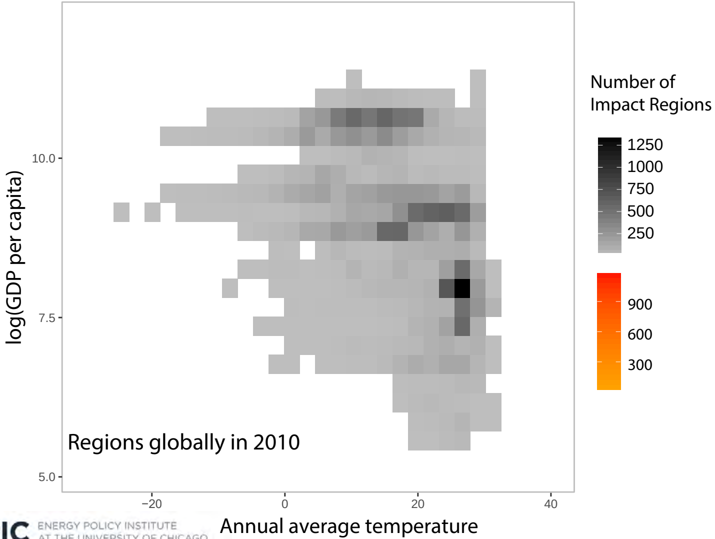
Example: today's mortality response to hot days in sample (ages 65+)



Example: today's mortality response to hot days globally (ages 65+)



Mortality: Representativeness in climate × income space



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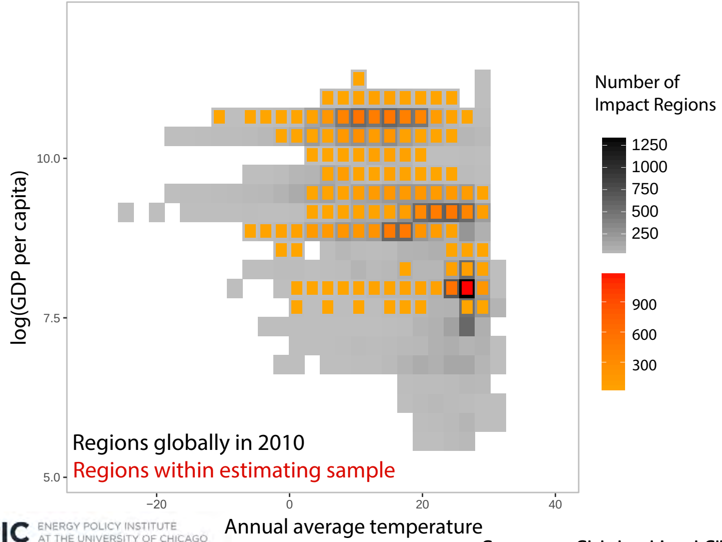

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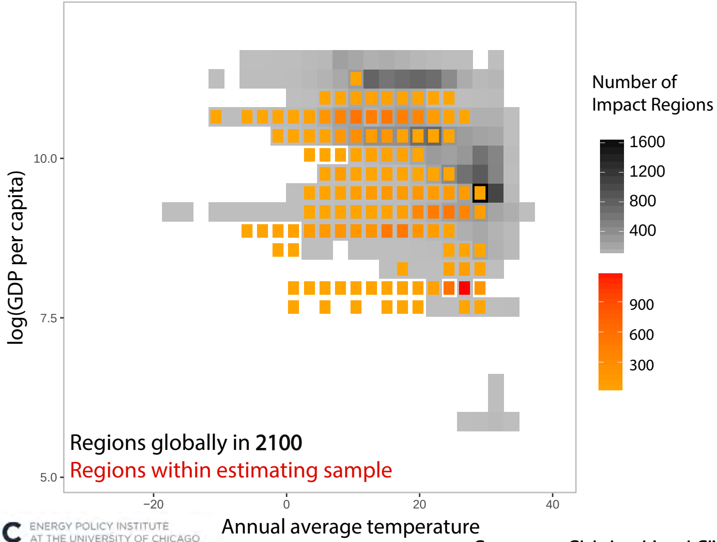
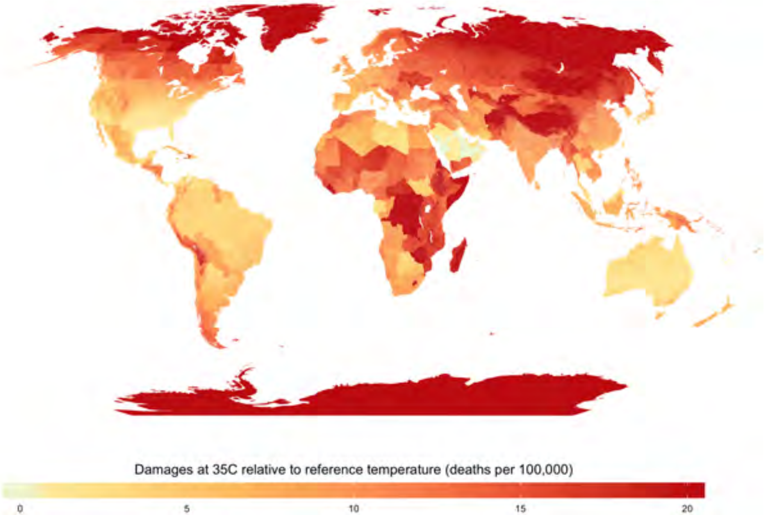
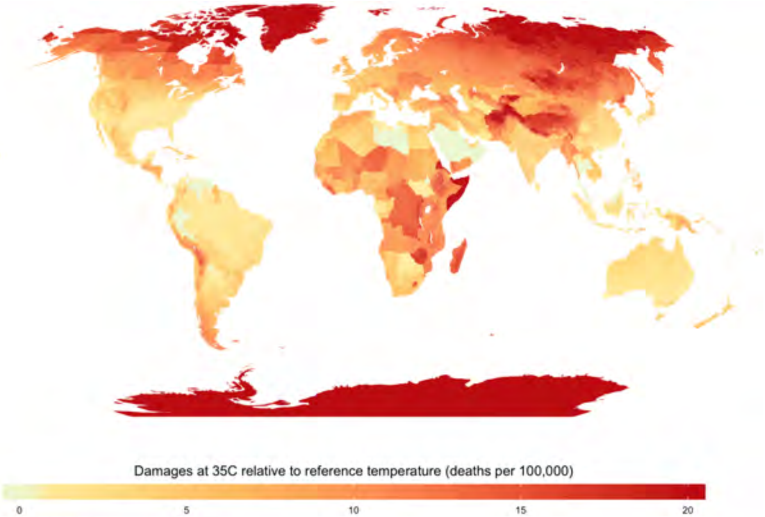


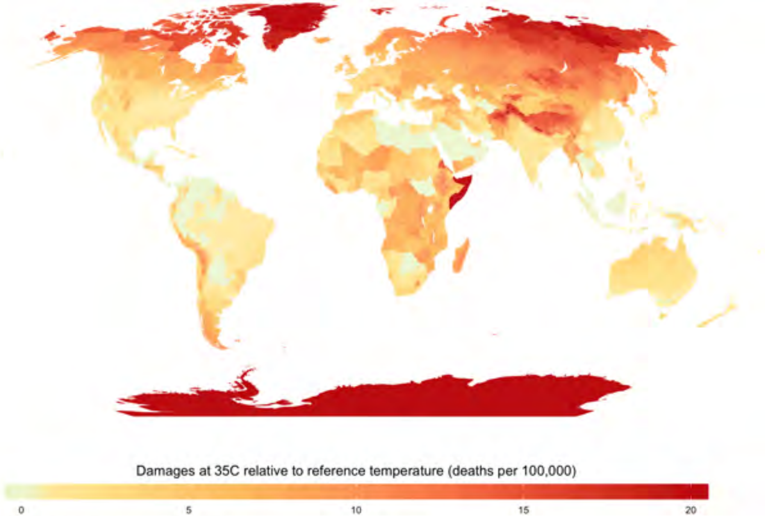
Example: Projecting mortality response to hot days (2020)



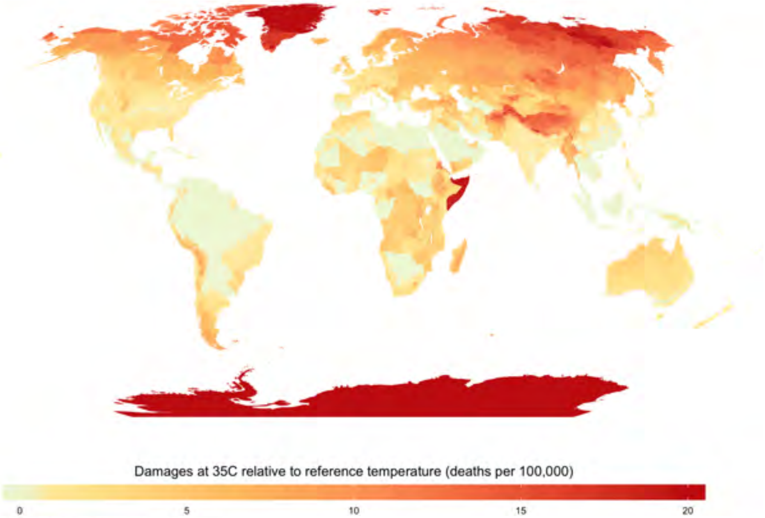
Example: Projecting mortality response to hot days (2050)



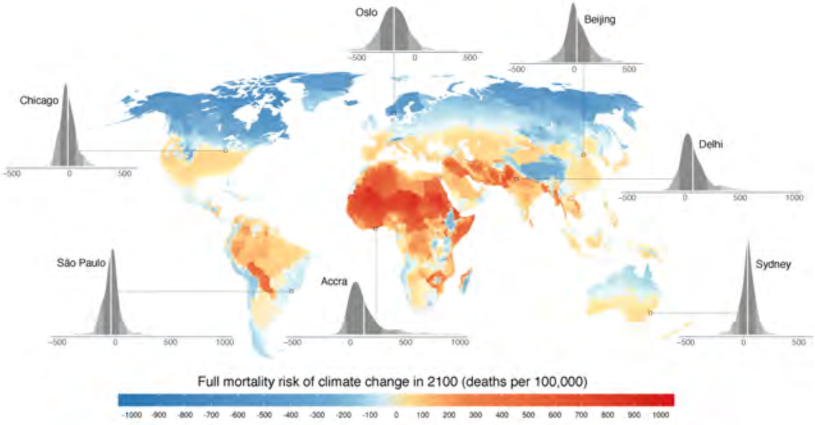
Example: Projecting mortality response to hot days (2080)



Example: Projecting mortality response to hot days (2100)



Mortality impacts are distributed unequally



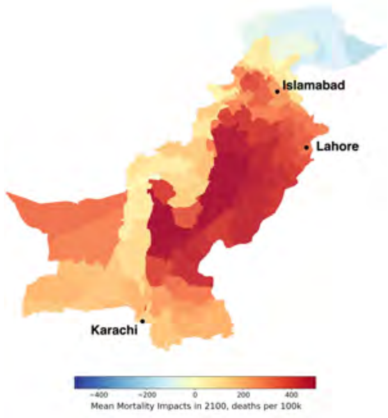
Δ Mortality + adapt. costs due to warming; 2099

Scenario: RCP8.5 & SSP3

Mortality impacts are distributed unequally, even within countries

Pakistan: 376 deaths/100k

Heart disease: 110 deaths/100k



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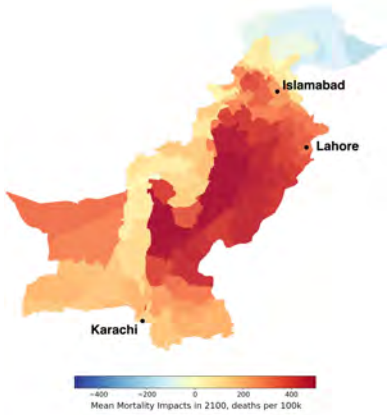
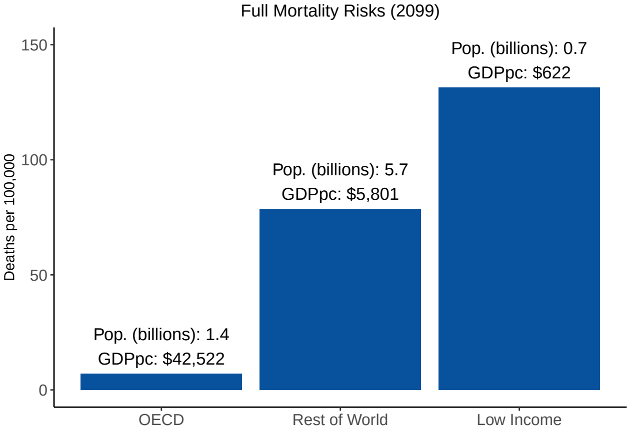


Ghana: 200 deaths/100k

Respiratory infections: 55 deaths/100k

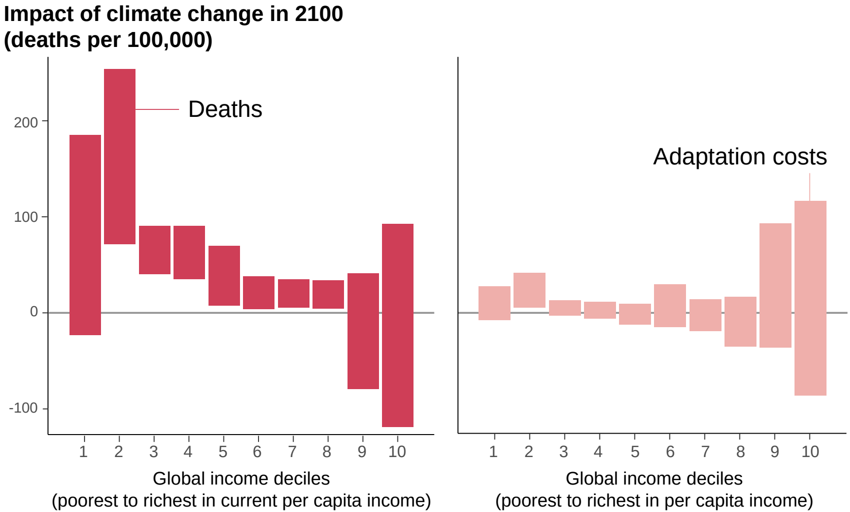
Scenario: RCP8.5 & SSP3; 2100

Mortality impacts across income groups

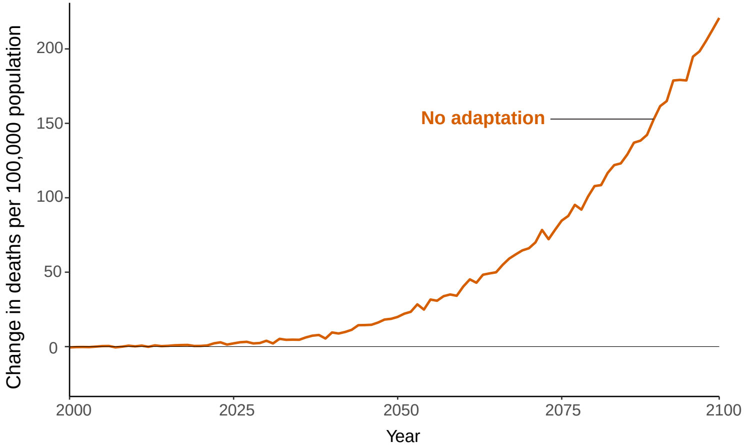


Income groups are defined based on 2021 income statistics at the national level.
World Bank definition of Low Income: $<$1085 (USD) GNIpc ($\approx$ \$3 per day).
Scenario: RCP8.5 & SSP3, Population and GDP from 2021

Mortality: distribution of burden by income



Global climate change damages to mortality



Scenario: RCP8.5 & SSP3

Current global average mortality rate: 770 deaths per 100,000

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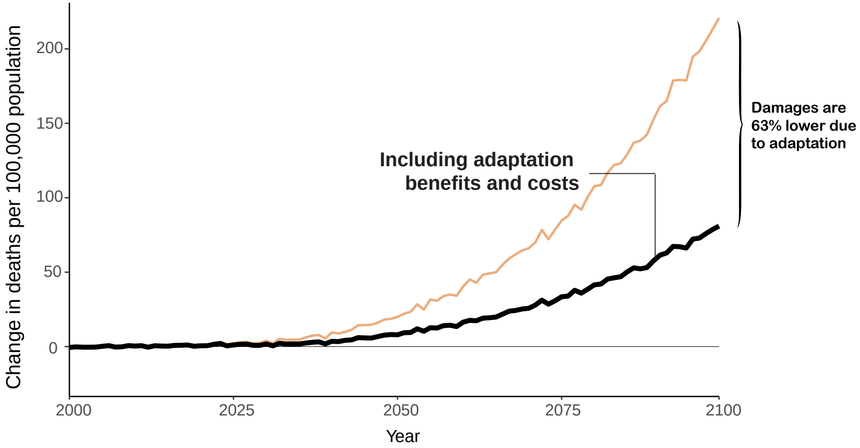
Global climate change damages to mortality



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Global climate change damages to mortality

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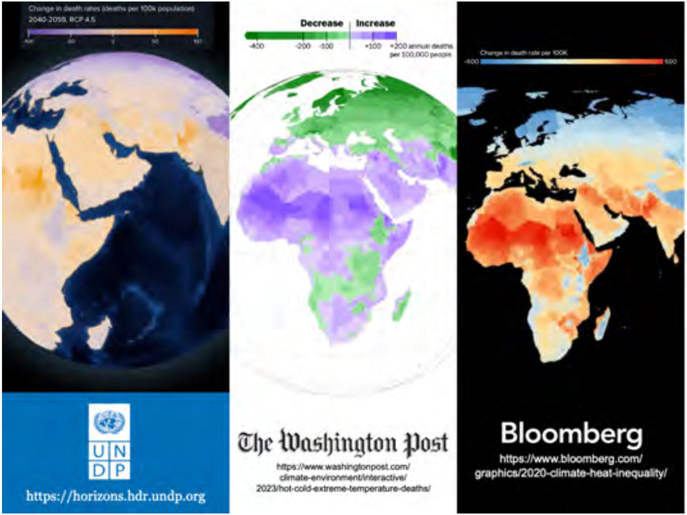
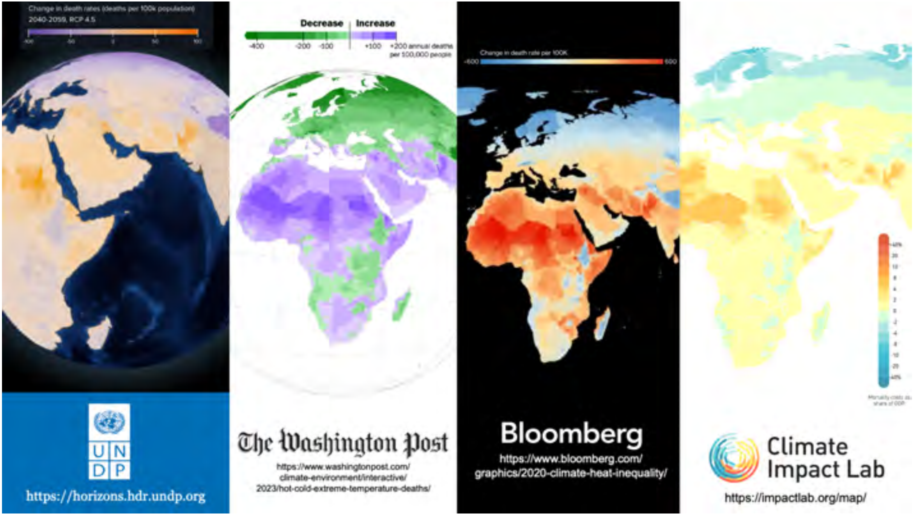


Global climate change damages to mortality



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   - Mortality
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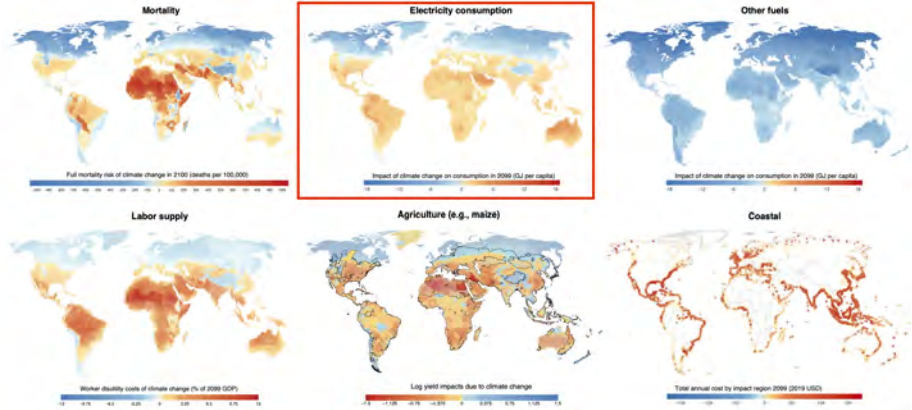
   - Climate Damages Year by Year
   - Social Cost of Carbon

Global climate change damages across sectors: 2099



Scenario: RCP8.5 & SSP3

Energy data coverage

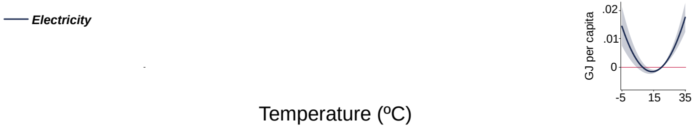
International Energy Agency (IEA) provides energy consumption data from 146 countries (1971 - 2012)

Estimating effects of temperature on energy use

$$Electricity\_consumption_{jt} = f(Temp_{jt}) + g(Precip_{jt}) + \underbrace{\alpha_{ji} + \delta_{wt}}_{\substack{\text{country-by-reporting regime} \\ \text{\& region-by-year controls}}} + \varepsilon_{jt}$$

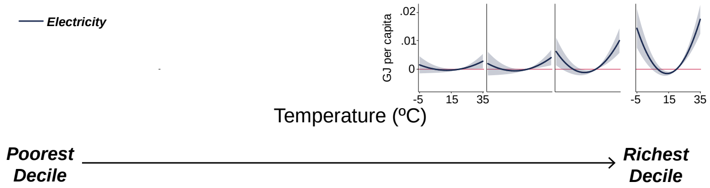
Electricity consumption observed in **country** j in **region** w under **reporting regime** i at **date** t.

Quantifying climate damages from electricity consumption



Poorest Decile → ***Richest Decile***

Quantifying climate damages from electricity consumption



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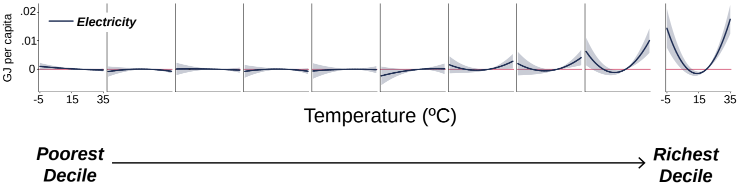

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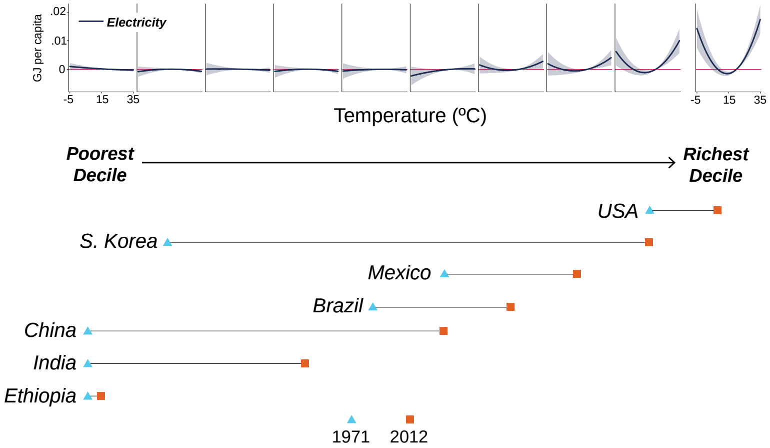

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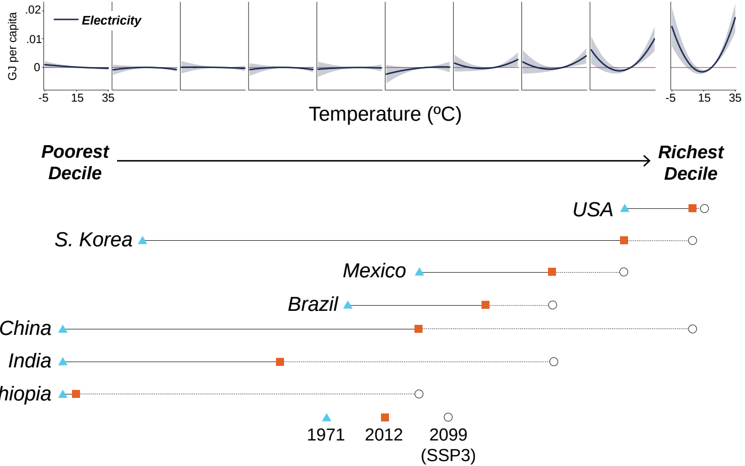

Scenario: RCP8.5 & SSP3

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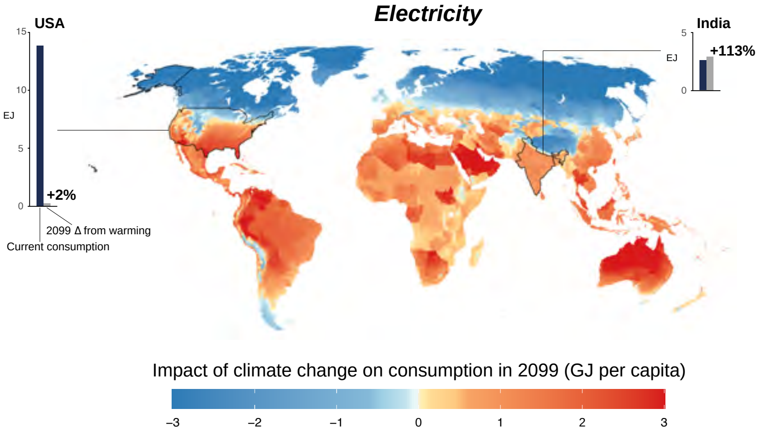

Scenario: RCP8.5 & SSP3

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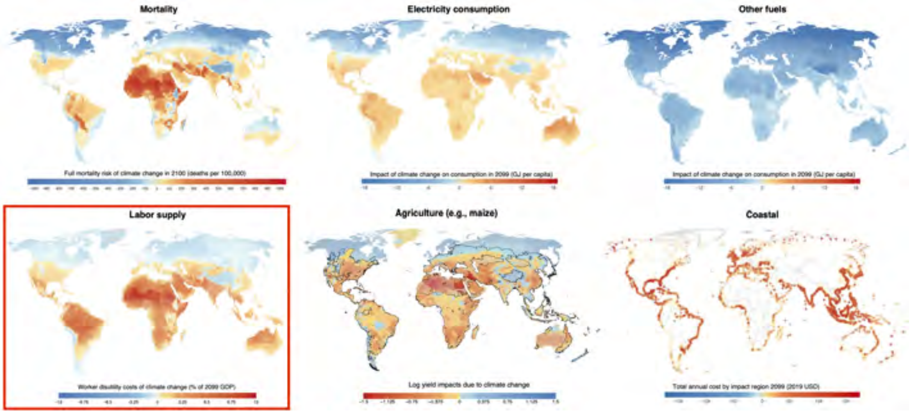
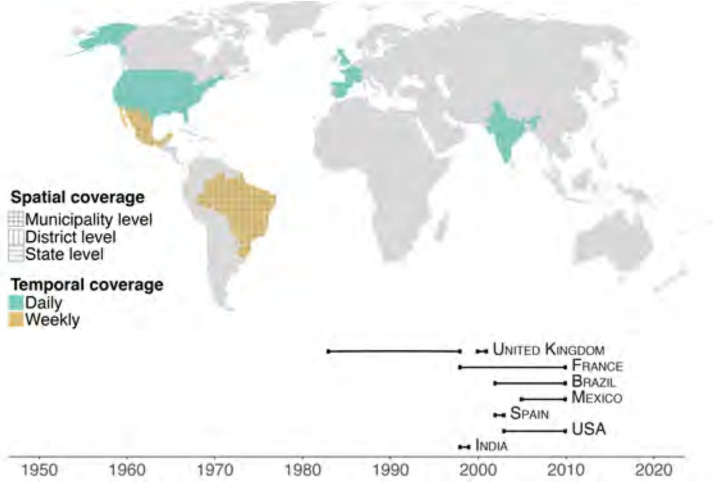
Global climate change damages across sectors



Labor data coverage

Time use and labor force surveys representing $\sim 30\%$ of the global population



Estimating effects of temperature on labor supply

- Hourly wages are fixed for workers, so they must express labor disutility through daily labor supply decisions
- **Separate responses for Low- and High- Risk Workers:**

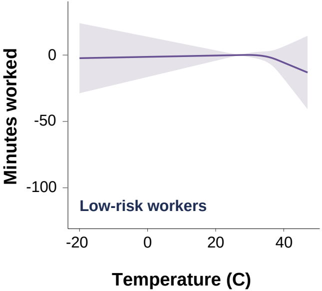
$$\underbrace{Labor_{i,r,t}}_{\text{work mins.}} = \underbrace{f_r(T_{j,t})}_{\text{restrict cubic spline in max daily temp.}}$$

$$+\theta_{1,r}Precip_{j,t} + \underbrace{\theta_{2,r}Precip^2_{j,t}}_{\text{precipitation}} + \underbrace{\lambda_r X_i}_{\text{covariates}} + \underbrace{\delta_{j,r} + \psi_{c,w,r} + \kappa_{c,w,r} + \phi_{d,r}}_{\text{fixed effects}} + \epsilon_{i,r,t}$$

Work minutes observed for **individual** i of **risk-group** r in **region** j at **date** t.

Labor supply response to temperature

- **High risk workers:** Agriculture, mining, construction, manufacturing
- **Low risk workers:** All other sectors



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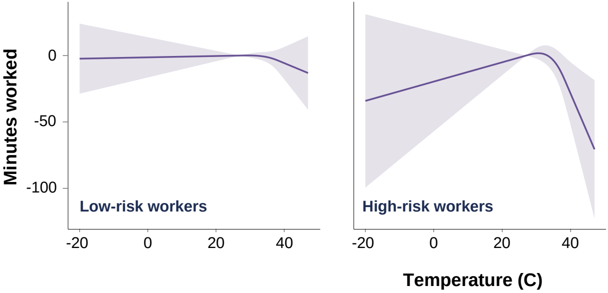

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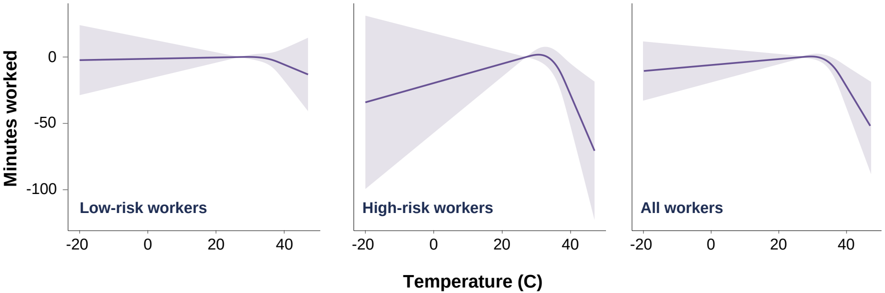

From labor supply to labor disutility

Annual temp. realization depends on climate C: $\mathbf{T} \equiv \{T_t(C)\}_{t=1}^{365}$

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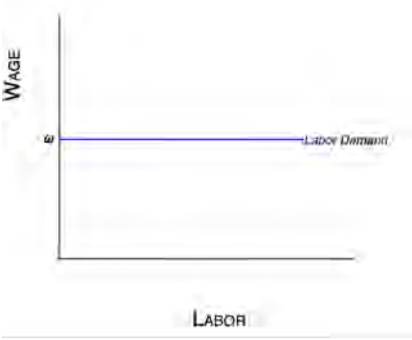
Daily Labor Market Equilibrium



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When daily temp. is realized, workers optimize by changing labor supply

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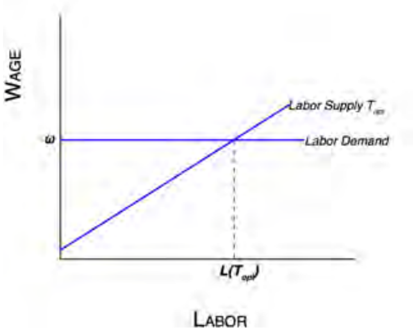

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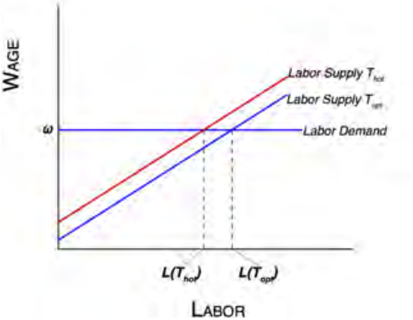

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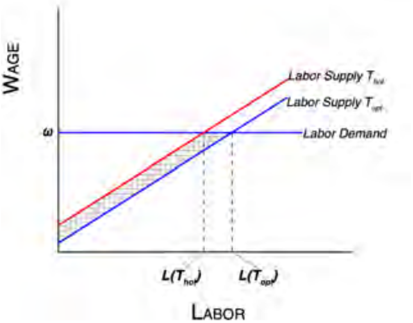

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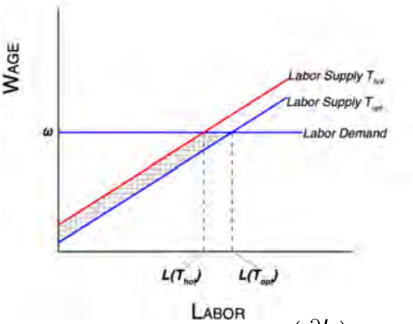
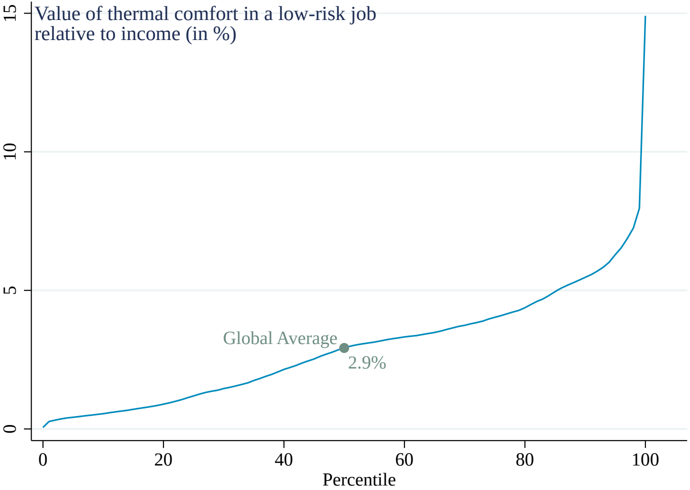


$$\text{Disutility from Temp.} = \frac{\partial Disutility}{\partial T} = L\left[\frac{\partial wage}{\partial T}\right] = \frac{wage\left(\frac{\partial L}{\partial T}\right)}{\epsilon}$$

Where ϵ is the Frisch elasticity = 0.5 (Chetty et al. 2011)

Quantifying labor disutility (today)



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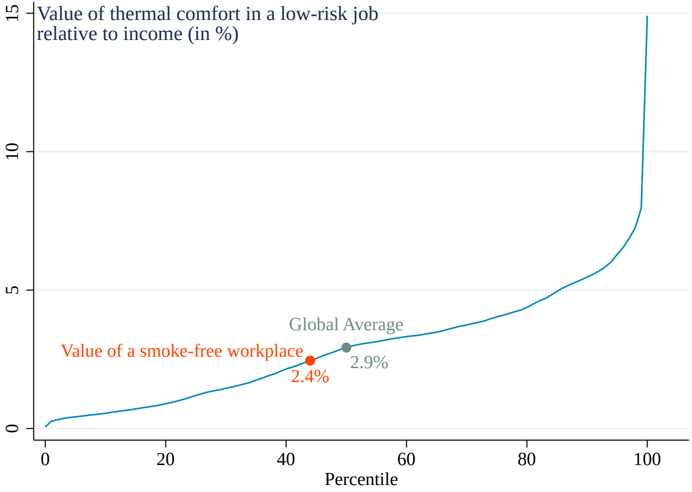

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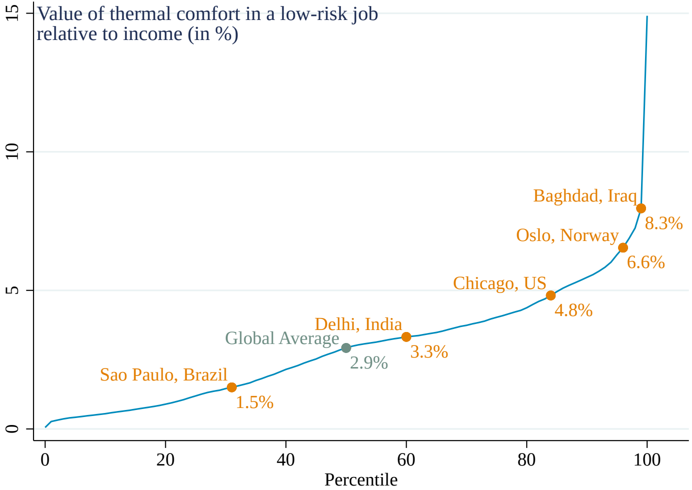

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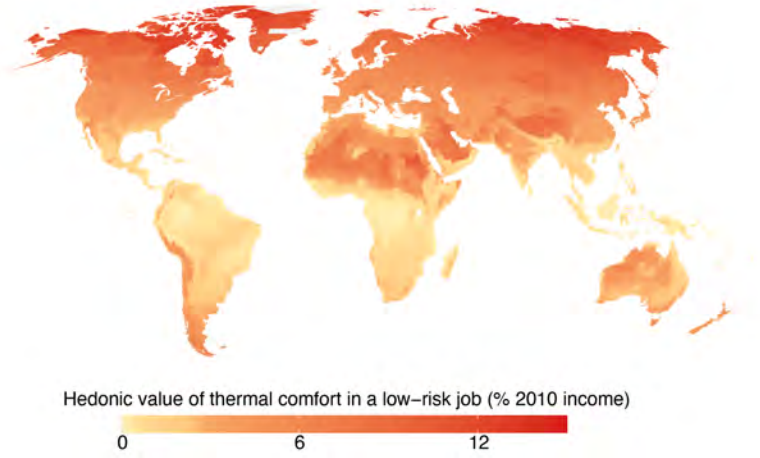
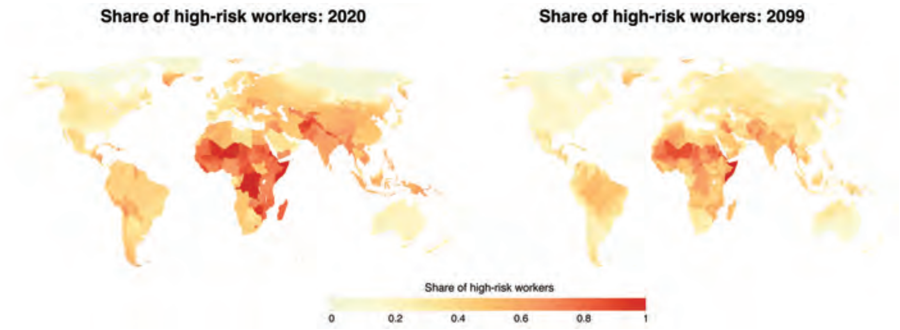
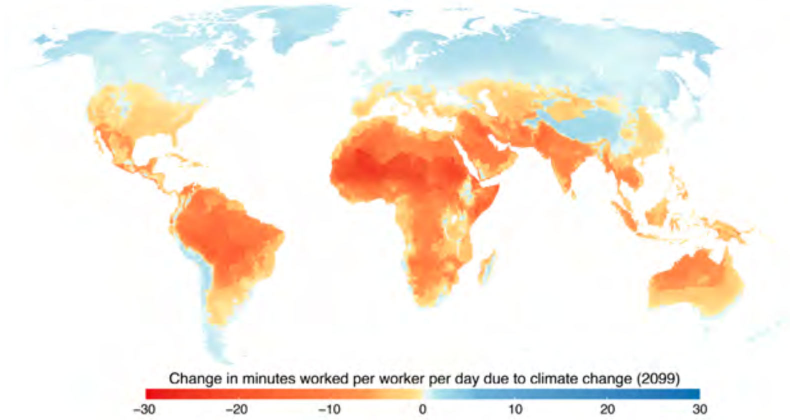


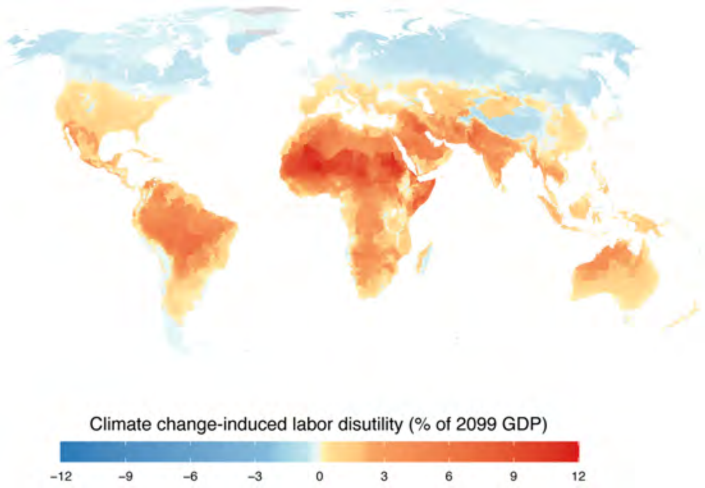
Projecting the share of high-risk workers as a function of future long-run temperatures and income



Combining this with temperature projections, we can calculate the impact of climate change on labor supply



And the impact of climate change on labor disutility



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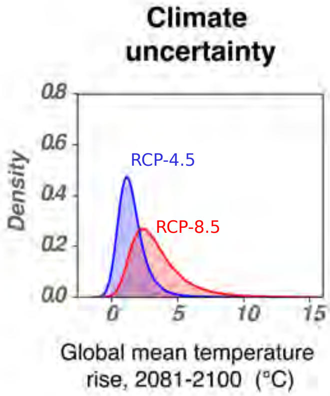
Multiple sources of uncertainty in climate change impacts



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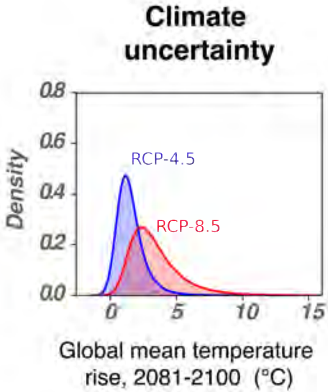
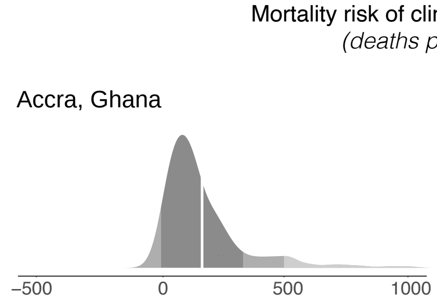


Additional sources of uncertainty: emissions and socioeconomic scenarios

Uncertainty in mortality impacts of climate change

Accra: ~8% probability deaths are >500/100k
~75% probability deaths are >malaria deaths today



Scenario: RCP8.5 & SSP3

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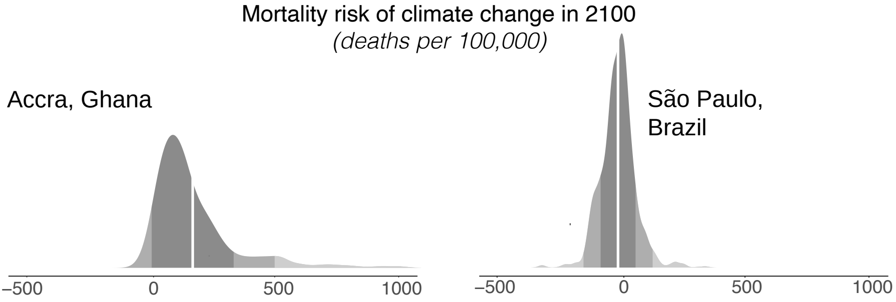
Uncertainty in mortality impacts of climate change

Accra: 8% probability deaths are >500/100k
$\sim$75% probability deaths are >malaria deaths today

São Paolo: 0% probability deaths are >500/100k
$\sim$40% probability deaths are >lung cancer deaths today



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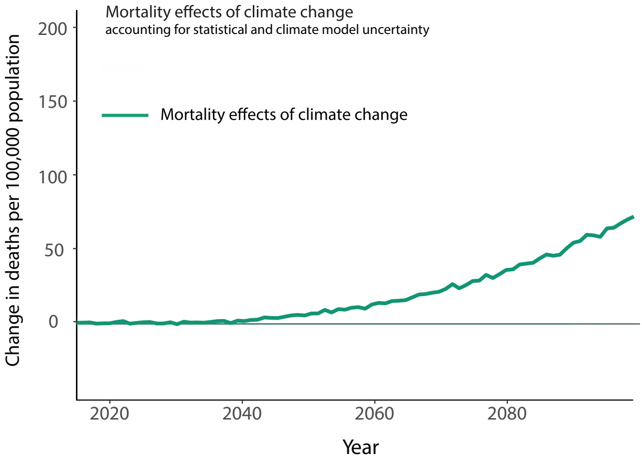

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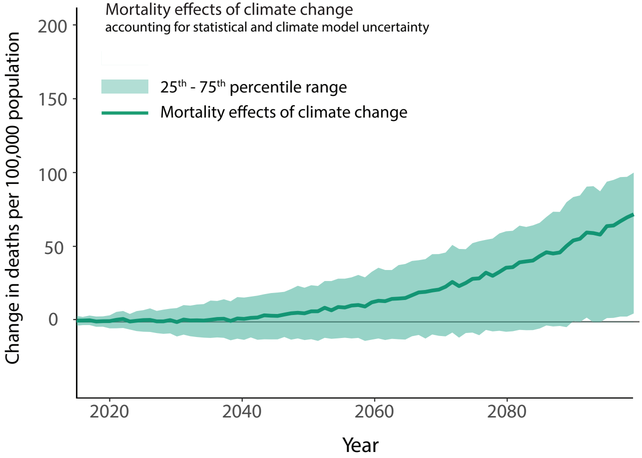

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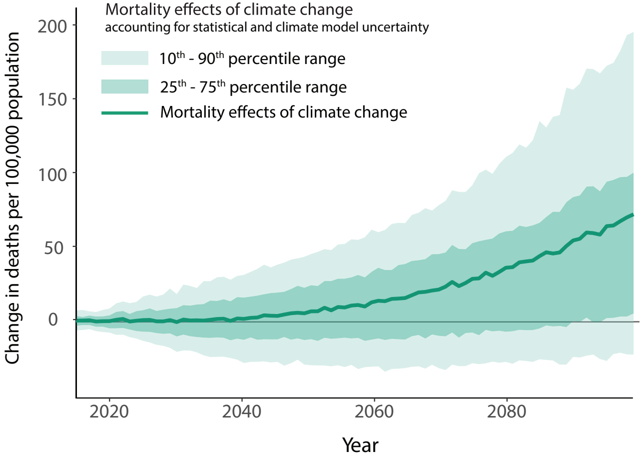

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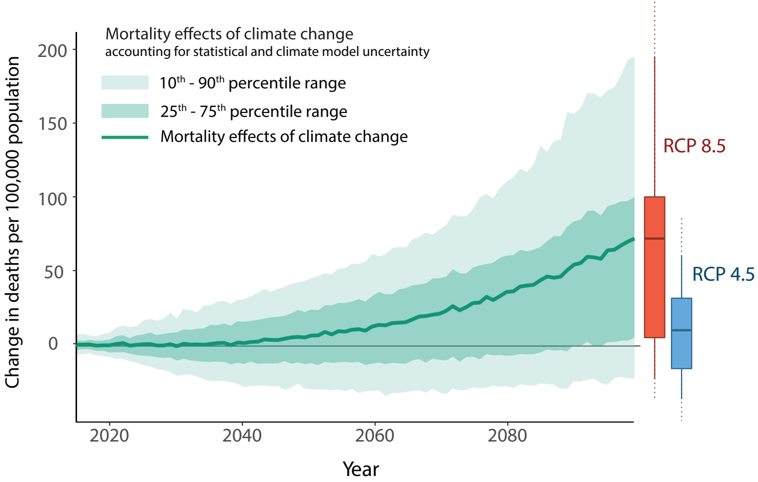

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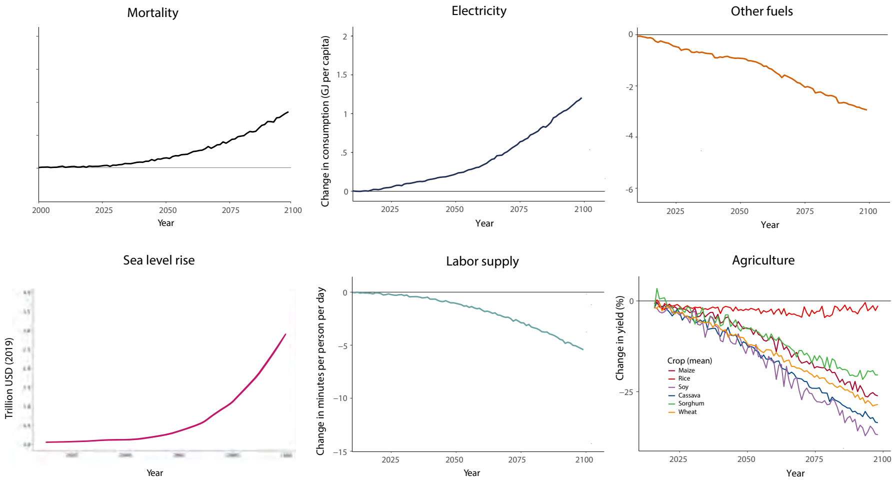

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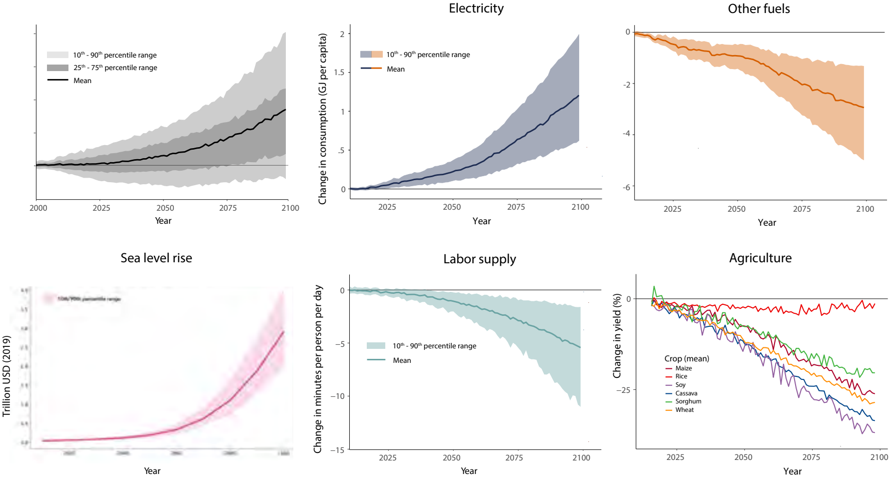
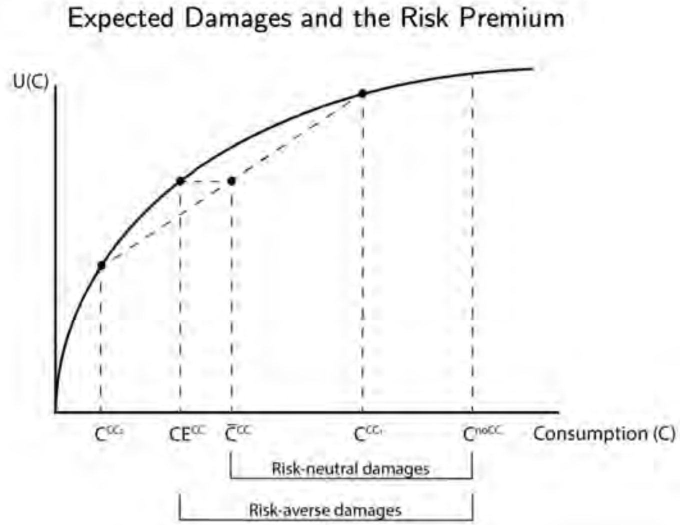


Scenario: RCP8.5 & SSP3

Valuing uncertainty in global impacts of climate change



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Aggregating total climate damages across sectors

Mortality — heat and cold deaths

All-cause mortality (<5) All-cause mortality (>64)

All-cause mortality (5-64)

Agriculture — crop yields

Maize Wheat Rice

Soybean Sorghum Cassava

Energy — energy and electricity demand

Electricity consumption Other fuels consumption

Labor — labor supply & disamenity

High risk labor Low risk labor

Coastal — sea level rise and storm damages

Sea level rise inundation SLR $\times$ tropical cyclone surge

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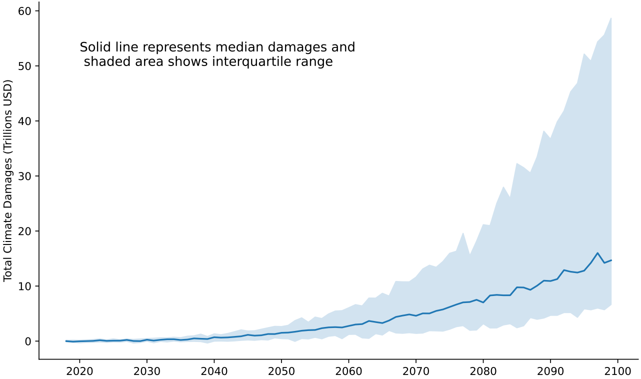
Integration — valuing marginal damages

Intertemporal discounting Valuing inequality

Pricing risk

Aggregating total climate damages across regions

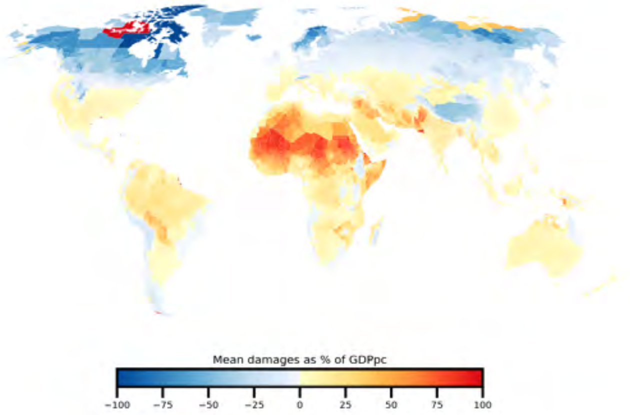


Global GDP in 2021: 96.1 Trillion USD

Scenario: RCP8.5 & SSP3

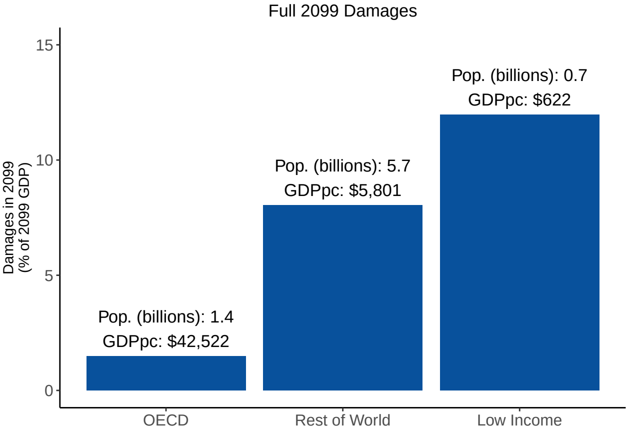
Aggregating total climate damages across regions

Combined Damages in 2099



Scenario: RCP8.5 & SSP3

Aggregate damages are borne disproportionately by today's poor



Income groups are defined based on 2021 income statistics at the national level.
World Bank definition of Low Income: $<$1085 (USD) GNIpc ($\approx$ \$3 per day).
Scenario: RCP8.5 & SSP3, Population and GDP from 2021

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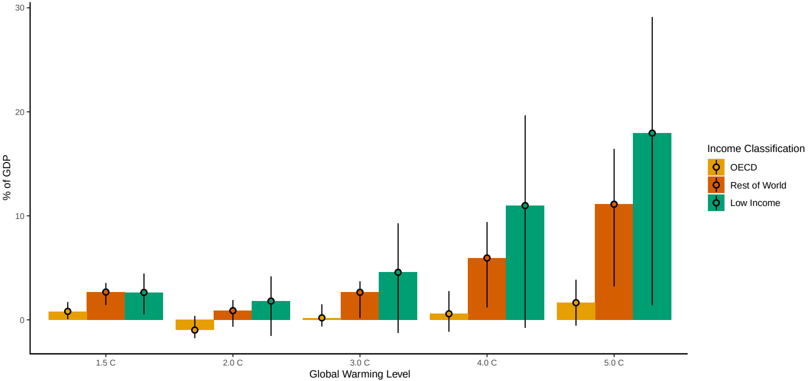


Jina, Carleton, Hultgren, Rode et al (in prep.)

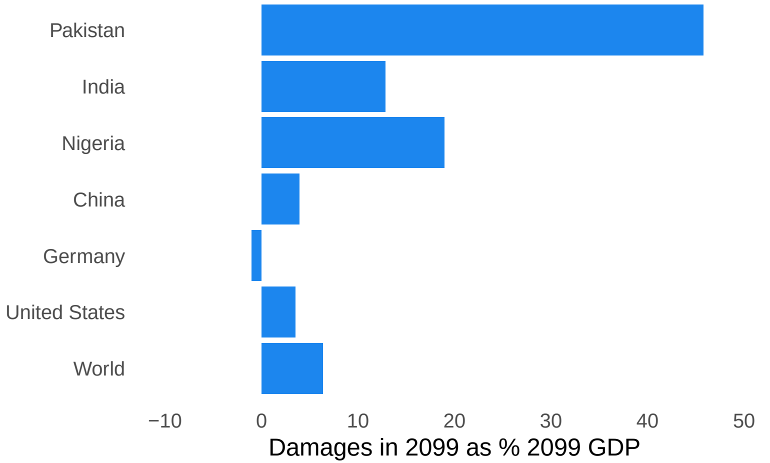
Climate damages by country

How costly are damages across countries?

Scenario: RCP8.5 & SSP3

Climate damages by country

How costly are damages across countries?



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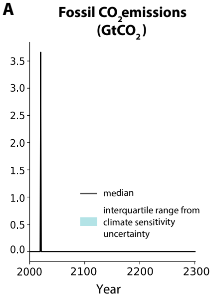
The Social Cost of Carbon

The most important number you've never heard of

The Social Cost of Carbon (SCC) - the monetary value of the damages imposed by the release of one additional ton of carbon dioxide.

Calculating a Social Cost of Carbon



Interquartile range generated by resampling ∼100,000 FAIR input parameters to capture the full range of climate sensitivity uncertainty. Climate damages are based on RFF socioeconomic and emissions scenarios.

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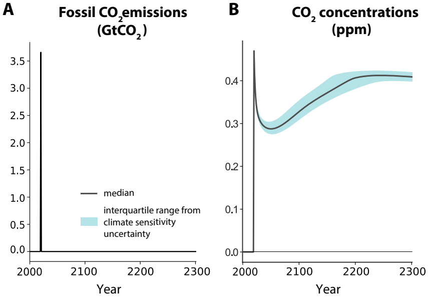

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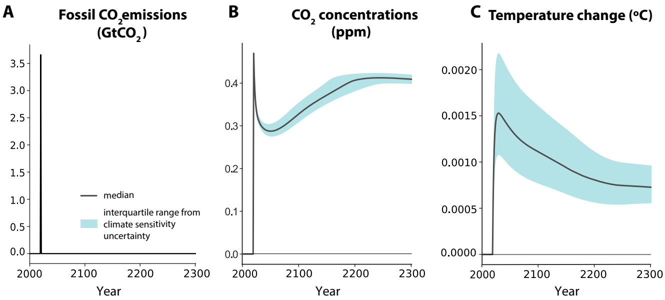

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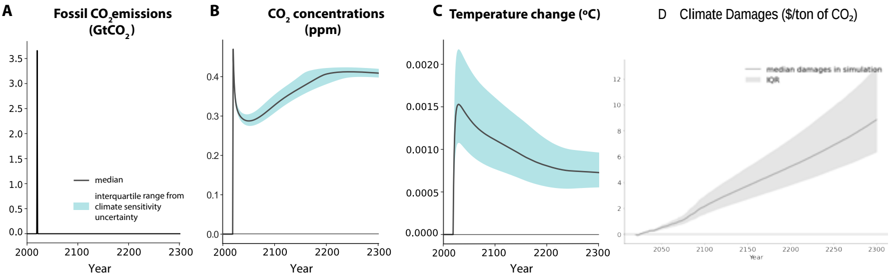

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Monetary damages from current emissions

Total CO_2 emissions since 1790: 1.96 trillion

How costly are current annual emissions?

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DSCIM Social Cost of Carbon: $189

Current World Annual CO_2 Emissions: 37,000 Mt

$\Longrightarrow$ **Resulting Economic Damages: ~7 Trillion USD**

Breakdown of Social Cost of Carbon

How costly are damages to rich versus poor regions?

Income Groups	Population (billions)	**SCC** Contribution (USD)
OECD	1.4	-$11.3
Rest of World	5.8	$186.2
Low Income	0.7	$14.1
Total	7.9	$189

Population shares: OECD (17%) Low Income (9%) RoW (74%)
Income groups are defined using 2021 data.
Scenario: RCP8.5 & SSP3
Source: World Bank (2022) and CIL

Empirically founded SCCs vs Original IAM Approach

	Original IAM Approach	DSCIM

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	Original IAM Approach	DSCIM
Empirically-based damage functions	X	✓
Subnational heterogeneity	X	✓
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Complete set of sectors	?	X
Social cost of carbon	**$51**	**$189**

DSCIM estimates include:
Mortality, electricity, heating fuels, agriculture, labor disutility, coastal damages, all with Ramsey discounting and RFF socioeconomic/emission projections

Aggregating impacts across sectors with step-by-step economics

A large SCC literature underscores the importance of declining marginal utility of consumption for:

1. **Valuing uncertainty** (e.g., Cai and Lontzek, 2016)
2. **"Equity weighting"** across contemporaneous individuals (e.g., Anthoff, Hepburn, and Tol, 2009)
3. **Endogenous discounting** driven by economic growth and its uncertainty (e.g., Gollier and Weitzman, 2010)

DSCIM is able to integrate insights from this literature:

- Uncertainty across econometrics, socioeconomics and climate science
- Heterogeneity across 24,378 regions
- Endogenous discounting based on scenario assumptions + impacts

A Data-Driven Social Cost of Carbon

Sectors: Mortality, energy, labor, agriculture, coastal

	Constant discounting: $\delta = 2\%^*$			Endogenous discounting†
	Mean over uncertainty	**Certainty equivalent**	**Equity weighting**	**Ramsey w/ uncertainty**
RCP4.5	\$43	\$58	\$77	\$156
RCP7.0	\$71	\$116	\$112	\$941

Assumptions: $\eta = 2$ and $\rho = 0$; *SSP3; †SSPs 2-4

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$\rightarrow$ Obama-era SCC: \$51

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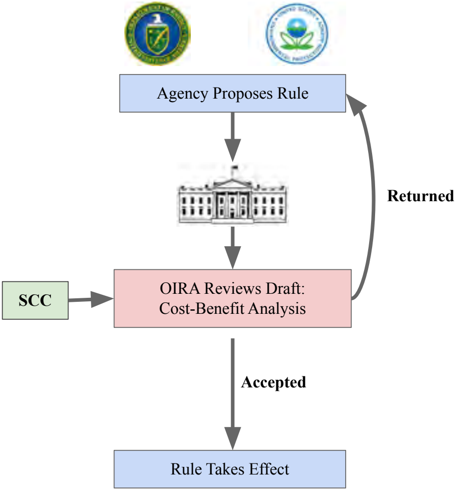
→ EPA probabilistic socioeconomic and emissions trajectories: \$190

→ Also used to compute SC-methane (\$850) and SC-nitrous oxide (\$49,000)

The SCC in US Policy

- Agency rules must go through OIRA review before they can be released for comment or enacted.
- OIRA compares the costs and benefits of policies, including the value of changes in emissions.



SCC in action

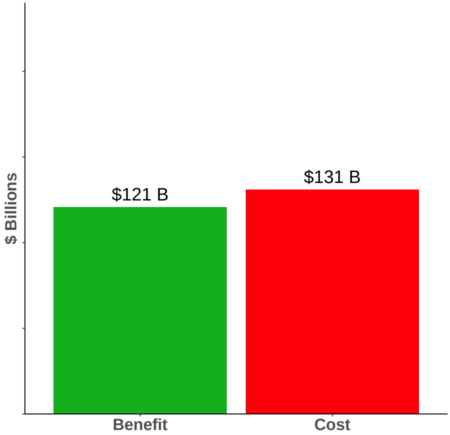
Policy: Corporate Average Fuel Economy (CAFE) Standards for Model Years 2024—2026 Passenger Cars and Light Trucks (RIN 2127–AM34)

Summary: More stringent fuel economy standards for passenger cars and light trucks.

SCC in action

Policy outcome:

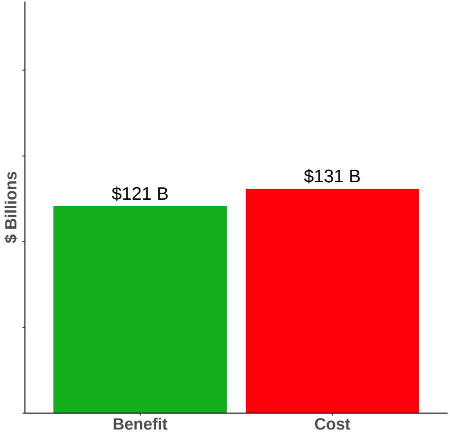
SCC = $0



SCC in action

Policy outcome: Do not pass

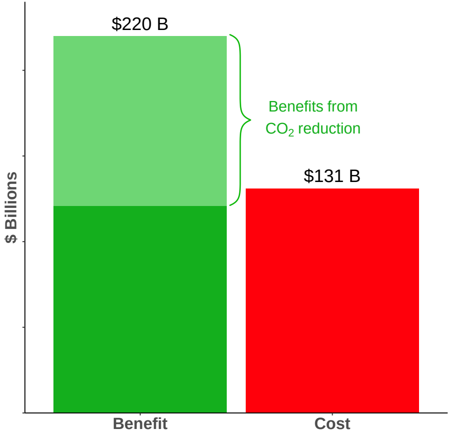
SCC = $0



SCC in action

Policy outcome:

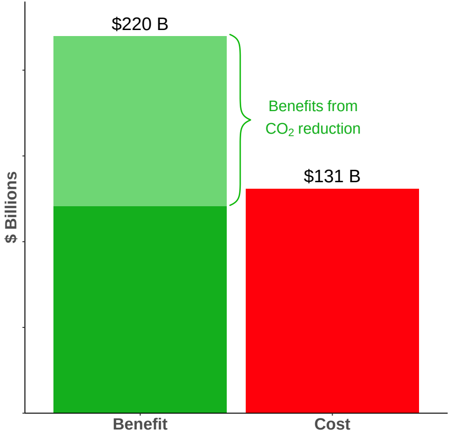
$$SCC = \$189$$



SCC in action

Policy outcome: Pass

SCC = $189



Conclusion: New understanding of damages

- Advances in economics and climate science allow for quantification of the global- and local-level impacts of climate change
- Damages are larger and more heterogeneous than previously thought
- Costs especially concentrated in today's poor and hot places

Conclusion: Updated SCC

- Social Cost of Carbon (SCC) is important summary measure of climate damages
- New SCC estimates are ∼4 times larger than previously estimated
- These estimates suggest that current yearly emissions correspond to ∼$7 Trillion damages (∼7% current global GDP)
- An updated SCC is important for guiding policy

Conclusion: More impact sectors

- ☑ **Mortality** — heat and cold deaths
- ☑ **Agriculture** — crop yields for seven major crops
- ☑ **Energy** — energy and electricity demand
- ☑ **Labor** — labor supply effects
- ☑ **Coastal** — sea level rise and storm damages
- ☑ **Inequality** — Distribution of damages across 5 sectors
- ☑ **Conflict** — large-scale violent conflict
- ☑ **Crime** — interpersonal violent crime
- ☐ **Migration** — international and within-country
- ☐ **Manufacturing** — projections using existing research
- ☐ **Wildfires** — preliminary analysis

Appendix

RCP Climate Scenarios