Topics in Development Economics (EC9C0)

Week 4: Climate change
Lecture 7

Stefano Caria

- The world is rapidly getting warmer due to man-made emissions of heat-trapping gasses.

- Under current policies, the world is on course to be 2.7 degree celsius warmer than in pre-industrial times.

- This will result in major increases in extreme weather events (extreme heat, droughts, floods, etc..), sea level rise, ocean acidification, etc... (check out this visualization)

- Preventing this from happening is one of the most important policy challenges of our times.


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1. The cost of global warming and the puzzle of adaptation

- This week, we will look at how applied economists can contribute to our understanding of the costs of climate change and the optimal policy response.
- Today, we will focus on the crucial issue of how to estimate the economic damage of global warming.
- This will require discussing the possibility and extent of human adaptation to climate change.

2. How much to invest in mitigation?

- On Thursday, we will move to a discussion of the optimal policy response.

- Global warming can be mitigated, at a cost:
    - How much do we want to invest in mitigation?
    - What is the optimal way to do it?

Roadmap

Basic definitions and trends

Estimating the economic damage of climate change

Empirical evidence on adaptation

Adaptation through technologies or through migration?

Papers to read

In this initial short section I will introduce some foundational concepts and describe key trends.

I will largely follow the discussion in Hsiang and Kopp (2018).

I will also borrow from the articles in Carbon Brief — a web publication that covers climate science.

The climate and the weather

The climate is the joint probability distribution describing the state of the atmosphere, ocean, and freshwater systems.

We typically refer to specific draws from this distribution as the *weather*.

We can describe the climate intuitively by reporting moments of this probability distribution.

E.g. *global mean surface temperature* intuitively captures how hot the earth's climate is.

Global warming

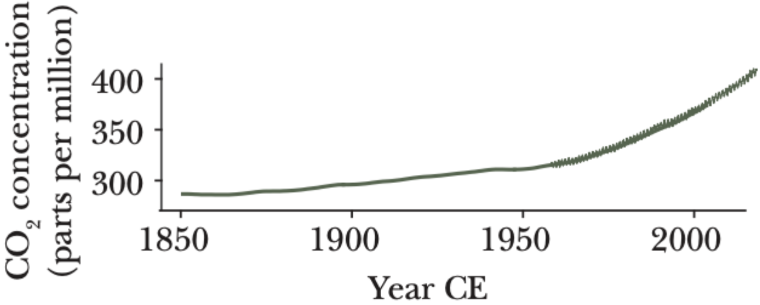
Our climate is changing due to the greenhouse effect.

The burning of fossil fuels and other human activities result in the release of greenhouse gases in the atmosphere.

These gases trap heat in the atmosphere, raising average temperatures.

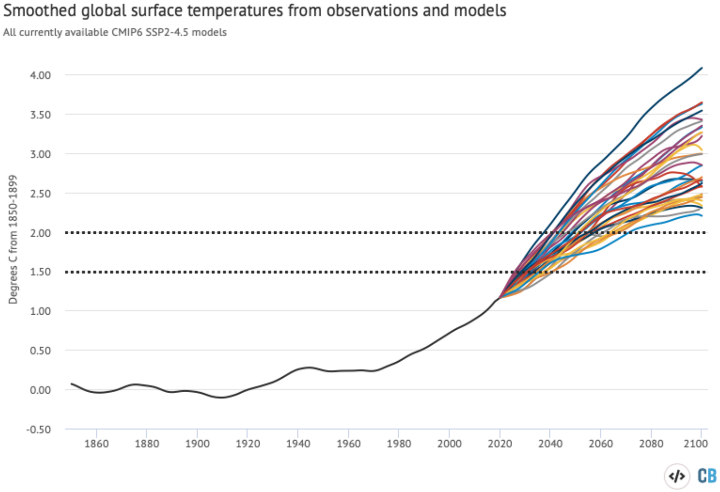
The key greenhouse gas is CO2.

The amount of CO2 in the atmosphere has been increasing rapidly



From 278 ppm in preindustrial times to 409 ppm today.

And the world temperature has already increased by more than 1 degree



Smoothed global surface temperatures from observations and models

All currently available CMIP6 SSP2-4.5 models

Smoothed average of historical observations from NASA; NOAA; Met Office Hadley Centre/UEA; Berkeley Earth; Cowtan and Way from 1850-2020. Warming relative to 2020-2100 from smoothed versions of all currently available CMIP6 models running the SSP2-4.5 scenario. Chart by Carbon Brief using Highcharts.

Future warming and goals

Under the Paris Agreements, nations have committed to keep temperature increases by 2100 ‘well below 2 degrees’.

A recent report of the International Panel on Climate Change (IPCC) identifies 1.5 degrees as a more desirable goal.

Partly, this is to limit the likelihood of tipping points.

How hot will our world be in the future?

Global circulation models (GCM) project climate changes on the basis of a given emission pathway.

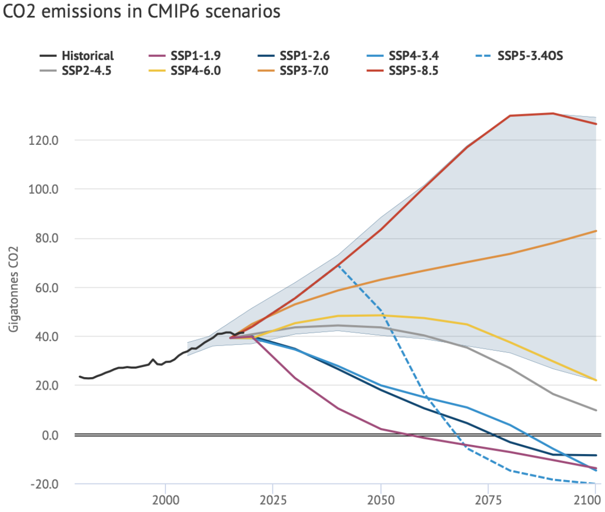
As future emissions are unknown, these models do not produce forecast, but rather simulate scenarios.

The IPCC analysis is based on 3 main representative concentration pathways (RCPs):

- RCP8.5 (the ‘worst case’ scenario): CO2 concentration reaches 936 ppm by 2100.
- RCP4.5 (moderate): CO2 concentration reaches 538 ppm.
- RCP2.6 (low): CO2 concentration reaches to 421 ppm.

These RCPs are matched with shared socio-economic pathways (SSPs) which describe a set of economic and social changes consistent with the respective RCP.

Different pathways



SSP2-RCP4.5 is considered as the scenario most aligned with current policies.

Uncertainty

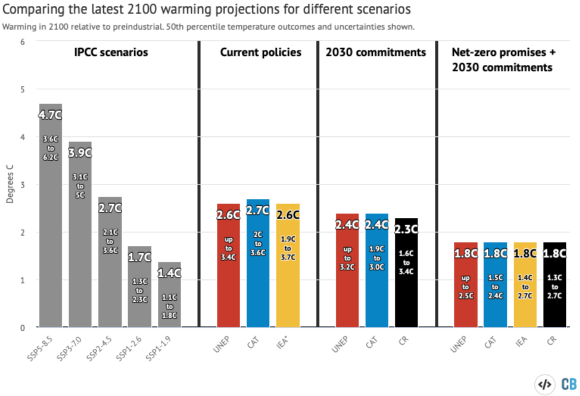
For a given emission scenario, we are still uncertain on the final amount of warming as our models of the climate are imperfect.

The Couple Models Intercomparison Project (CMIP) combines estimates from tens of models, simulated under different assumptions. We are currently at CMIP6.

The dispersion of the simulation results gives us a sense of the modelling uncertainty.

Note also that these models do not take into account the possibility of tipping points.

Current estimates of future warming



Comparing the latest 2100 warming projections for different scenarios

Warming in 2100 relative to preindustrial. 50th percentile temperature outcomes and uncertainties shown.

Compilation of the latest 2100 median warming projections from UNEP, CAT, IEA and CR as of 9 November 2021, compared to the assessed warming values for the five shared socioeconomic pathway (SSP) scenarios highlighted in the recent IPCC AR6 WG1 report. Both central estimates and uncertainty ranges are shown. Note that the IEA current policy scenario (STEPS) is in-between policies in place today and 2030 commitments. Chart by Carbon Brief using Highcharts.

See this Carbon Brief piece.

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Papers to read

What will be the economic cost of climate change?

GCM models describe how the basic features of the climate will change for a given pathway of emissions.

These changes often impose economic costs:

- Lower agricultural productivity.
- Higher costs to cool indoor temperature.
- (in some areas, there will actually be benefits)

Estimating the damage function, which maps changes in the climate to economic costs, is key to formulate climate policy.

I will describe the progress economist have made, following closely the discussion in Auffhammer (2018).

The need for a counterfactual

To estimate the damage function we need to compare the value of an outcome (e.g. GDP) with and without climate change.

This is particularly hard to do, for two reasons:

- Our comparison across or within units may be confounded by omitted variable bias;
- Humans have the capacity to adapt to climate change, reducing its economic cost.

Adaptation

Humans can adapt to climate change in two ways:

- On the intensive margin, you can engage more in behaviors that decreases costs (e.g. use more air-conditioning).
- On the extensive margin, you can change technology (e.g. buy air-conditioning), occupation, location.

→ Short run adaptation differs from long-run adaptation.

- LR adaptation is often more effective (e.g. better technologies available in the future, more mobility, etc..)
- But not always (e.g. when adaptation relies on depletable resources)

Adaptation by switching crop

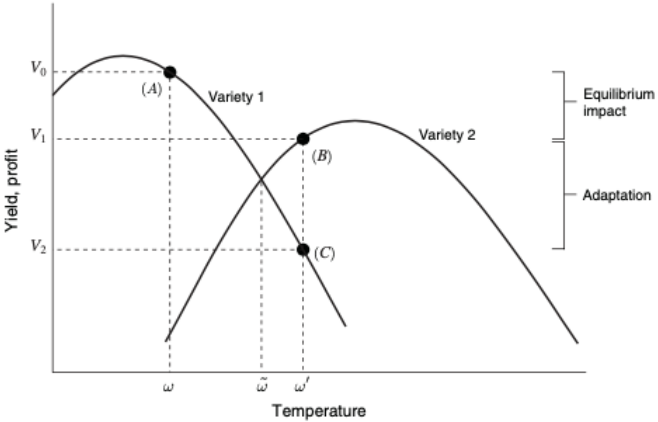


FIGURE 2. PRODUCTIVITY OF TWO DIFFERENT CORN VARIETIES AS A FUNCTION OF TEMPERATURE

Two methods to estimate the damage function

There are two econometric methods available for this exercise:

1. The cross-sectional method.
2. The panel method.

The cross-sectional method

We compare locations that have a different climate:

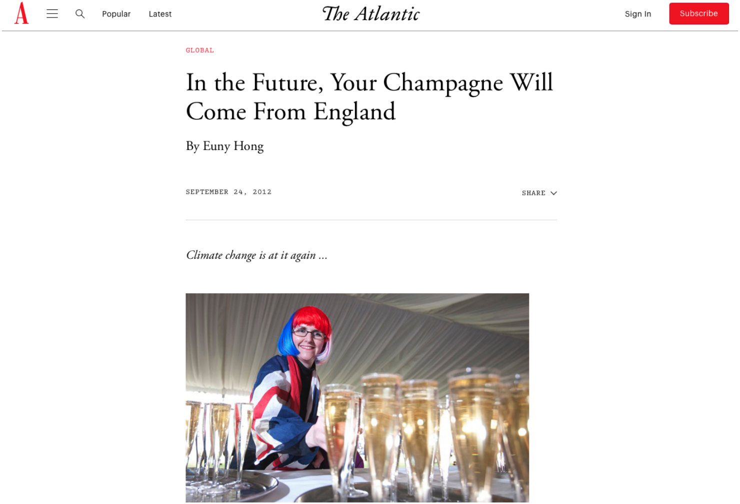
$$y_i = \alpha + \beta Climate_i + \gamma x_i + u_i \tag{1}$$

Key advantage: (some) adaptation is accounted for.

But there are three problems:

1. Particularly susceptible to omitted variable bias.
2. Adaptation may not happen due to switching costs.
3. Behaviour is also determined by beliefs about the future.

Example: beliefs about future warming drive investment in English wine



GLOBAL

In the Future, Your Champagne Will Come From England

By Euny Hong

SEPTEMBER 24, 2012

Climate change is at it again ...

The panel method

We study how the outcomes of the same location responds to the weather.

$$y_{it} = \alpha + \beta Climate_{it} + \theta_i + u_{it} \tag{2}$$

Strength: (time-invariant) omitted variables are controlled for.

But there is a big problem:

- Adaptation may be incomplete.
- If adaptation occurs late you overstate damages.

A hybrid method: long-differences (Burke and Emerick 2016)

Compute averages of y and $Climate$ for long time-periods.
Study how changes in average climate affect average y.

$$\Delta\bar{y}_i = \beta\Delta\overline{Climate}_i + u_i \tag{3}$$

- (Time-invariant) omitted variables are controlled for thanks to differencing.
- Long-term averages get us closer to long-term adaptation.
- Though adaptation in the coming 50 years may still look very different from adaptation in past 50 years.

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What do Burke and Emerick 2016 find?

$$\Delta\bar{y}_{is} = \beta_1 \Delta\overline{GDD}_{is,l_0-l_1} + \beta_2 \Delta\overline{GDD}_{is,>l_1} + \beta_3 \Delta\overline{Prec}_{is} + \alpha_s + u_i \quad (4)$$

- Use county-year data on US corn productivity.
- And daily temperature data.
- They calculate growing degree days (GDD): the amount of time a crop is exposed to a favourable range of temperature $l_0 - l_1$.
- They take averages in 1978-82 and 1998-2002.
- β_2 is the coefficient of interest: the impact of excess heat on corn productivity.

Main findings

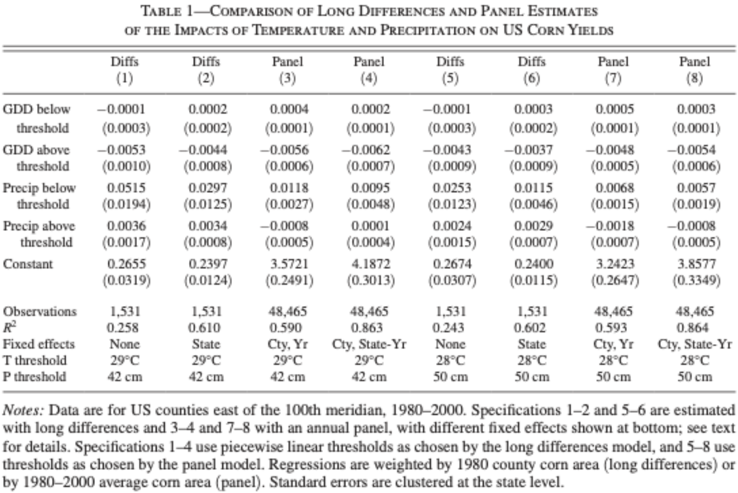


TABLE 1—COMPARISON OF LONG DIFFERENCES AND PANEL ESTIMATES OF THE IMPACTS OF TEMPERATURE AND PRECIPITATION ON US CORN YIELDS

	Diffs (1)	Diffs (2)	Panel (3)	Panel (4)	Diffs (5)	Diffs (6)	Panel (7)	Panel (8)
GDD below threshold	−0.0001	0.0002	0.0004	0.0002	−0.0001	0.0003	0.0005	0.0003
	(0.0003)	(0.0002)	(0.0001)	(0.0001)	(0.0003)	(0.0002)	(0.0001)	(0.0001)
GDD above threshold	−0.0053	−0.0044	−0.0056	−0.0062	−0.0043	−0.0037	−0.0048	−0.0054
	(0.0010)	(0.0008)	(0.0006)	(0.0007)	(0.0009)	(0.0009)	(0.0005)	(0.0006)
Precip below threshold	0.0515	0.0297	0.0118	0.0095	0.0253	0.0115	0.0068	0.0057
	(0.0194)	(0.0125)	(0.0027)	(0.0048)	(0.0123)	(0.0046)	(0.0015)	(0.0019)
Precip above threshold	0.0036	0.0034	−0.0008	0.0001	0.0024	0.0029	−0.0018	−0.0008
	(0.0017)	(0.0008)	(0.0005)	(0.0004)	(0.0015)	(0.0007)	(0.0007)	(0.0005)
Constant	0.2655	0.2397	3.5721	4.1872	0.2674	0.2400	3.2423	3.8577
	(0.0319)	(0.0124)	(0.2491)	(0.3013)	(0.0307)	(0.0115)	(0.2647)	(0.3349)
Observations	1,531	1,531	48,465	48,465	1,531	1,531	48,465	48,465
R^2	0.258	0.610	0.590	0.863	0.243	0.602	0.593	0.864
Fixed effects	None	State	Cty, Yr	Cty, State-Yr	None	State	Cty, Yr	Cty, State-Yr
T threshold	29°C	29°C	29°C	29°C	28°C	28°C	28°C	28°C
P threshold	42 cm	42 cm	42 cm	42 cm	50 cm	50 cm	50 cm	50 cm

Notes: Data are for US counties east of the 100th meridian, 1980–2000. Specifications 1–2 and 5–6 are estimated with long differences and 3–4 and 7–8 with an annual panel, with different fixed effects shown at bottom; see text for details. Specifications 1–4 use piecewise linear thresholds as chosen by the long differences model, and 5–8 use thresholds as chosen by the panel model. Regressions are weighted by 1980 county corn area (long differences) or by 1980–2000 average corn area (panel). Standard errors are clustered at the state level.

Two take-aways

1. An extra day of excess heat decreases yields by .5 percent.
2. The difference between the panel estimator and the long differences estimator is small and insignificant

→ Consistent with large damages and limited adaptation.

A recent study on Brazil: Albert et al 2021

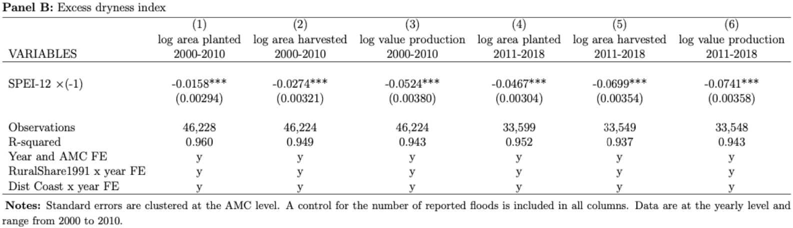
- Study the implications of dryness on agricultural output, capital flows, and migration in Brazil.
- Use drought data from (i) government reports, and (ii) a climatological measure of dryness (SPEI).
- Measure short and long term impacts using the following specifications

$$y_{ot} = \alpha_o + \alpha_t + \beta_1 Dryness_{ot} + \Lambda Controls_{ot} + u_{ot} \tag{5}$$

$$y_{dr,2000-2010} = \alpha_r + \beta_1 Dryness_{dr} + \Gamma Controls_{dr} + \epsilon_{dr} \tag{6}$$

o is a municipality, r a macro-region, d denotes a differenced variable.

In the short, dryness causes major agricultural losses

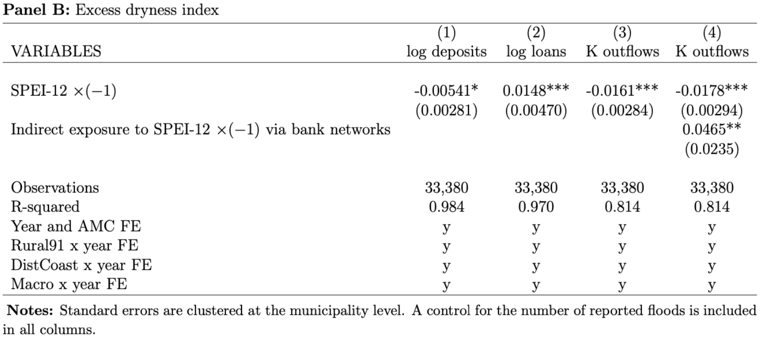


Panel B: Excess dryness index

VARIABLES	(1) log area planted 2000-2010	(2) log area harvested 2000-2010	(3) log value production 2000-2010	(4) log area planted 2011-2018	(5) log area harvested 2011-2018	(6) log value production 2011-2018
SPEI-12 ×(-1)	-0.0158***	-0.0274***	-0.0524***	-0.0467***	-0.0699***	-0.0741***
	(0.00294)	(0.00321)	(0.00380)	(0.00304)	(0.00354)	(0.00358)
Observations	46,228	46,224	46,224	33,599	33,549	33,548
R-squared	0.960	0.949	0.943	0.952	0.937	0.943
Year and AMC FE	y	y	y	y	y	y
RuralShare1991 x year FE	y	y	y	y	y	y
Dist Coast x year FE	y	y	y	y	y	y

Notes: Standard errors are clustered at the AMC level. A control for the number of reported floods is included in all columns. Data are at the yearly level and range from 2000 to 2010.

In the short run, capital flows in to moderate losses

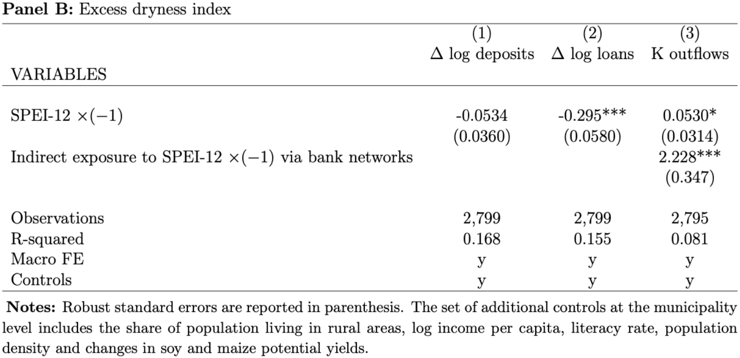


Panel B: Excess dryness index

VARIABLES	(1) log deposits	(2) log loans	(3) K outflows	(4) K outflows
SPEI-12 $\times(-1)$	-0.00541*	0.0148***	-0.0161***	-0.0178***
	(0.00281)	(0.00470)	(0.00284)	(0.00294)
Indirect exposure to SPEI-12 $\times(-1)$ via bank networks				0.0465**
				(0.0235)
Observations	33,380	33,380	33,380	33,380
R-squared	0.984	0.970	0.814	0.814
Year and AMC FE	y	y	y	y
Rural91 x year FE	y	y	y	y
DistCoast x year FE	y	y	y	y
Macro x year FE	y	y	y	y

Notes: Standard errors are clustered at the municipality level. A control for the number of reported floods is included in all columns.

In the long-run, however, capital flows out

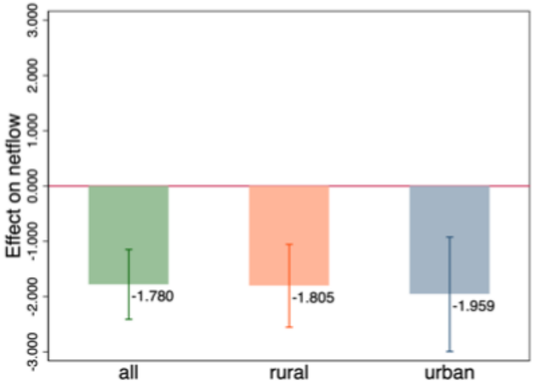


Panel B: Excess dryness index

VARIABLES	(1) Δ log deposits	(2) Δ log loans	(3) K outflows
SPEI-12 ×(−1)	-0.0534	-0.295***	0.0530*
	(0.0360)	(0.0580)	(0.0314)
Indirect exposure to SPEI-12 ×(−1) via bank networks			2.228***
			(0.347)
Observations	2,799	2,799	2,795
R-squared	0.168	0.155	0.081
Macro FE	y	y	y
Controls	y	y	y

Notes: Robust standard errors are reported in parenthesis. The set of additional controls at the municipality level includes the share of population living in rural areas, log income per capita, literacy rate, population density and changes in soy and maize potential yields.

And population shrinks



Implications

1. The implications of climate shocks can be very far reaching.

2. Short-run responses differ substantially from long-run responses

    - From the point of view of affected localities, short-term adaptation is stronger than long-term adaptation.

    - From the perspective of the whole economy, on the other hand, capital and labor flows may enhance efficiency.

Mortality costs: Carleton et al. 2022

$$\begin{aligned} &\textit{mortality effects of climate change} \\ &\quad = f(\boldsymbol{b}(Y_t, \boldsymbol{C}_t), \boldsymbol{c}(\boldsymbol{C}_t)) - f(\boldsymbol{b}(Y_t, \boldsymbol{C}_{t_0}), \boldsymbol{c}(\boldsymbol{C}_{t_0})), \end{aligned} \tag{2}$$

Breaking mortality costs down

$$\textit{mortality effects of climate change (without income growth or adaptation)} = f(\boldsymbol{b}(Y_{t_0}, \boldsymbol{C}_{t_0}), \boldsymbol{c}(\boldsymbol{C}_t)) - f(\boldsymbol{b}(Y_{t_0}, \boldsymbol{C}_{t_0}), \boldsymbol{c}(\boldsymbol{C}_{t_0})), \tag{2a}$$

$$\textit{mortality effects of climate change (without adaptation)} = f(\boldsymbol{b}(Y_t, \boldsymbol{C}_{t_0}), \boldsymbol{c}(\boldsymbol{C}_t)) - f(\boldsymbol{b}(Y_t, \boldsymbol{C}_{t_0}), \boldsymbol{c}(\boldsymbol{C}_{t_0})). \tag{2b}$$

Adding adaptation costs

$$
\begin{aligned}
&\textit{full mortality risk of climate change}\\
&\quad = VSL_t \underbrace{\left[f(\boldsymbol{b}(Y_t, \boldsymbol{C}_t), \boldsymbol{c}(\boldsymbol{C}_t)) - f(\boldsymbol{b}(Y_t, \boldsymbol{C}_{t_0}), \boldsymbol{c}(\boldsymbol{C}_{t_0})) \right]}_{\text{mortality effects of climate change}}\\
&\qquad + \underbrace{A(\boldsymbol{b}(Y_t, \boldsymbol{C}_t)) - A(\boldsymbol{b}(Y_t, \boldsymbol{C}_{t_0}))}_{\text{adaptation costs}}, \qquad (3)
\end{aligned}
$$

Estimation

The core empirical exercise consists of estimating response functions of the following form:

$$\begin{aligned} M_{ait} &= g_a(\boldsymbol{T}_{it},\ TMEAN_s, \log(GDPpc)_s) + q_{ca}(\boldsymbol{R}_{it}) + \alpha_{ai} \\ &\quad + \delta_{act} + \varepsilon_{ait}, \end{aligned} \tag{4}$$

- Estimate equation (4) for different age group and grid cells.
- Then estimate adaptation costs by using insights that, at the margin, adaptation costs and benefits have to equalize. Estimate adaptation benefits from (4).

Response functions

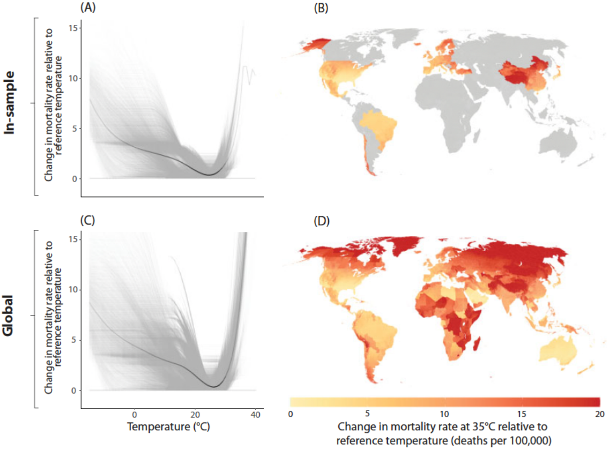


FIGURE III

Using Income and Climate to Predict Current Response Functions Globally (Age $>$ 64 Mortality Rate)

The mortality costs of climate change

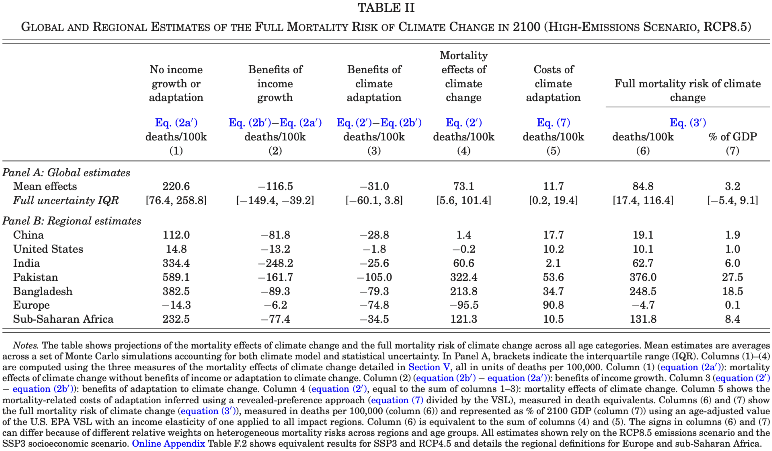


TABLE II

GLOBAL AND REGIONAL ESTIMATES OF THE FULL MORTALITY RISK OF CLIMATE CHANGE IN 2100 (HIGH-EMISSIONS SCENARIO, RCP8.5)

	No income growth or adaptation	Benefits of income growth	Benefits of climate adaptation	Mortality effects of climate change	Costs of climate adaptation	Full mortality risk of climate change	
	Eq. (2a′) deaths/100k (1)	Eq. (2b′)–Eq. (2a′) deaths/100k (2)	Eq. (2′)–Eq. (2b′) deaths/100k (3)	Eq. (2′) deaths/100k (4)	Eq. (7) deaths/100k (5)	Eq. (3′) deaths/100k (6)	% of GDP (7)
Panel A: Global estimates							
Mean effects	220.6	−116.5	−31.0	73.1	11.7	84.8	3.2
Full uncertainty IQR	[76.4, 258.8]	[−149.4, −39.2]	[−60.1, 3.8]	[5.6, 101.4]	[0.2, 19.4]	[17.4, 116.4]	[−5.4, 9.1]
Panel B: Regional estimates							
China	112.0	−81.8	−28.8	1.4	17.7	19.1	1.9
United States	14.8	−13.2	−1.8	−0.2	10.2	10.1	1.0
India	334.4	−248.2	−25.6	60.6	2.1	62.7	6.0
Pakistan	589.1	−161.7	−105.0	322.4	53.6	376.0	27.5
Bangladesh	382.5	−89.3	−79.3	213.8	34.7	248.5	18.5
Europe	−14.3	−6.2	−74.8	−95.5	90.8	−4.7	0.1
Sub-Saharan Africa	232.5	−77.4	−34.5	121.3	10.5	131.8	8.4

Notes. The table shows projections of the mortality effects of climate change and the full mortality risk of climate change across all age categories. Mean estimates are averages across a set of Monte Carlo simulations accounting for both climate model and statistical uncertainty. In Panel A, brackets indicate the interquartile range (IQR). Columns (1)–(4) are computed using the three measures of the mortality effects of climate change detailed in Section V, all in units of deaths per 100,000. Column (1) (equation (2a′)): mortality effects of climate change without benefits of income or adaptation to climate change. Column (2) (equation (2b′) − equation (2a′)): benefits of income growth. Column 3 (equation (2′) − equation (2b′)): benefits of adaptation to climate change. Column 4 (equation (2′), equal to the sum of columns 1–3): mortality effects of climate change. Column 5 shows the mortality-related costs of adaptation inferred using a revealed-preference approach (equation (7) divided by the VSL), measured in death equivalents. Columns (6) and (7) show the full mortality risk of climate change (equation (3′)), measured in deaths per 100,000 (column (6)) and represented as % of 2100 GDP (column (7)) using an age-adjusted value of the U.S. EPA VSL with an income elasticity of one applied to all impact regions. Column (6) is equivalent to the sum of columns (4) and (5). The signs in columns (6) and (7) can differ because of different relative weights on heterogeneous mortality risks across regions and age groups. All estimates shown rely on the RCP8.5 emissions scenario and the SSP3 socioeconomic scenario. Online Appendix Table F.2 shows equivalent results for SSP3 and RCP4.5 and details the regional definitions for Europe and sub-Saharan Africa.

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Papers to read

What drives adaptation?

- We often think that adaptation is mostly determined by technology.
    - E.g. scientists may develop heat-tolerant crops that reduce the impact of warming on agricultural yields.

- But a key fact about climate change is that its impacts differ substantially across space.

- This suggests that a second possibility is to adapt through migration.

The impacts of climate change differ across space

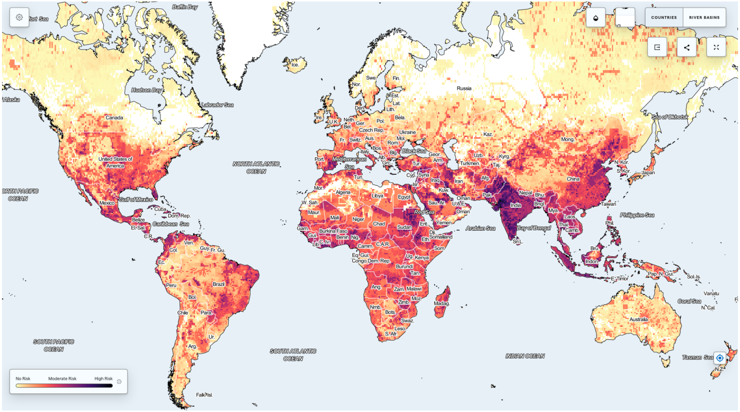


Figure: Overall vulnerability

From Global Hotspot Explorer: SSP2, 2 degrees of warming.

The impacts of climate change differ across space

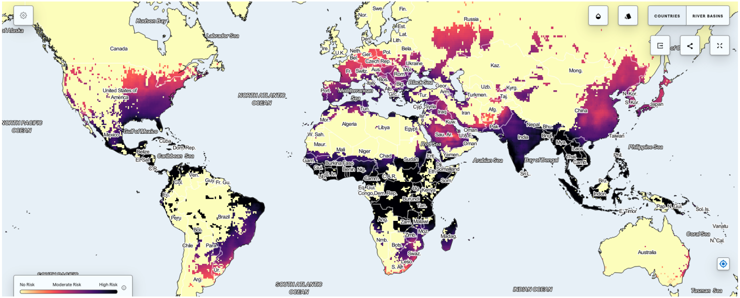


Figure: Heat stress

From Global Hotspot Explorer: SSP2, 2 degrees of warming.

The impacts of climate change differ across space

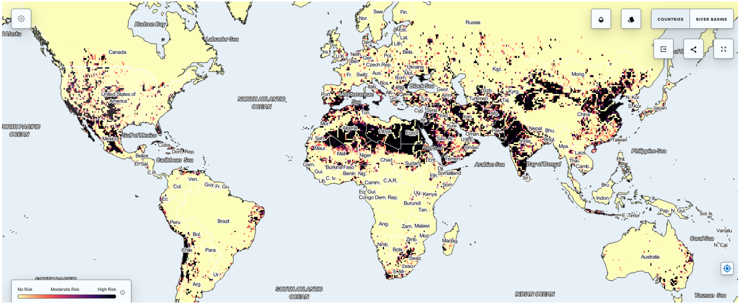


Figure: Water stress

From Global Hotspot Explorer: SSP2, 2 degrees of warming.

A lot of variation also within the same country

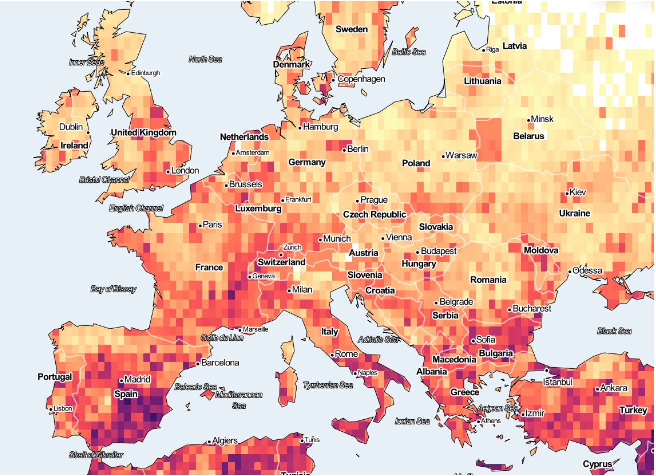


Figure: Overall vulnerability

From Global Hotspot Explorer: SSP2, 2 degrees of warming.

Migration as adaptation

Cruz and Rossi-Hansberg (2021) propose a model to estimate the importance of migration as an adaptation mechanism.

There are the key features:

- Dynamic model, spanning over 200 years.
- Fine spatial disaggregation.
- Includes endogenous migration and fertility.
- Includes innovation.
- Includes trade.
- Includes energy use and CO2 production.

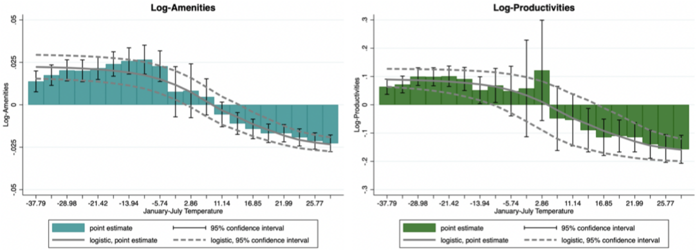
Estimates damage functions for productivities and amenities.

Two steps:

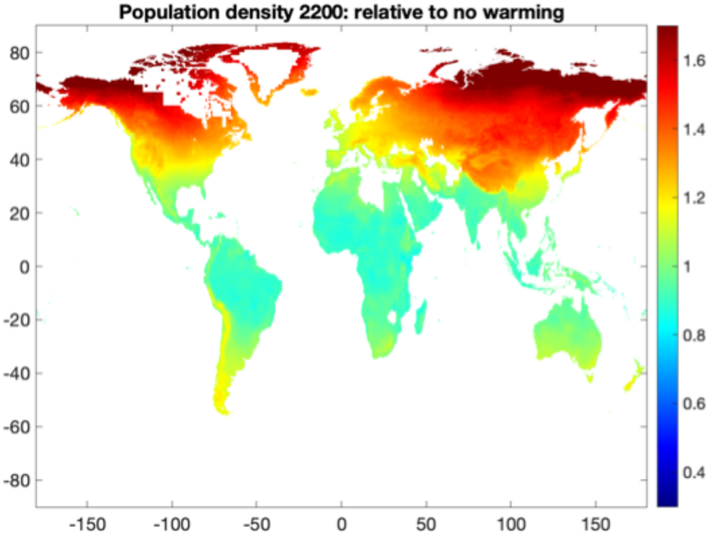
1. Use the model to estimate productivities, amenities and migration costs that rationalise the population distribution at time t.

2. Use the panel method to estimate how warming changes productivities and amenities.

The damage function by baseline temperature



Changes in population due to climate change



Migration due to climate change

- The authors model temperature increases along the RCP 8.5 scenario.

- Estimate that 600 million people (5.85% of the world population) will migrate due to climate change by 2200.

- Location close to the equator will have population densities 18 percent lower.

Overall, the world present discounted value of welfare will fall by almost 6 percent

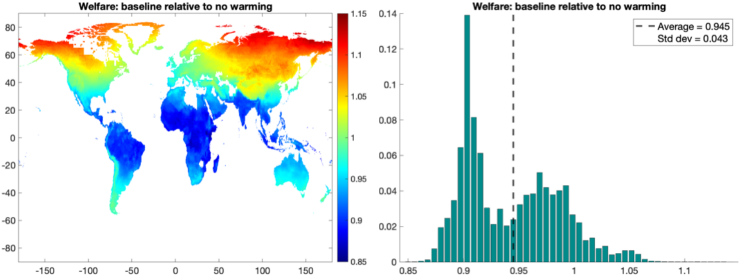


Figure 8: Welfare losses due to global warming.

Counterfactual experiments

The authors then try to simulate how migration, trade and innovation contribute to the overall cost

- 25% larger migration costs lead to welfare losses 1/3 larger.
- Trade has only a small effect.
- Innovation has an intermediate effect (which runs partly through migration: higher innovation pushes more people to migrate to climate resilient localities)

Increasing migration costs raises the cost of climate change substantially

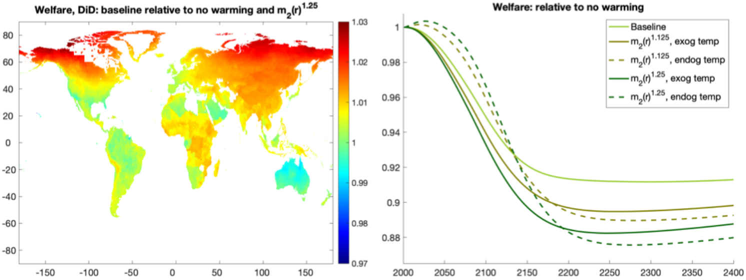


Figure 10: Welfare across different migration costs.

Roadmap

Basic definitions and trends

Estimating the economic damage of climate change

Empirical evidence on adaptation

Adaptation through technologies or through migration?

Papers to read

Papers

(*) Auffhammer, Maximilian. Quantifying economic damages from climate change. Journal of Economic Perspectives 32, no. 4 (2018): 33-52.
→ *Pages 33-46*.

Cruz, Jose-Luis, and Esteban Rossi-Hansberg. The economic geography of global warming. DP15803. CEPR Discussion Paper, 2021.
Albert, Christoph, Paula Bustos, and Jacopo Ponticelli. The Effects of Climate Change on Labor and Capital Reallocation. No. w28995. National Bureau of Economic Research, 2021.

Carleton et al. Valuing the global mortality consequences of climate change accounting for adaptation costs and benefits. The Quarterly Journal of Economics 137, no. 4 (2022): 2037-2105.

Burke, Marshall, and Kyle Emerick. Adaptation to climate change: Evidence from US agriculture American Economic Journal: Economic Policy 8, no. 3 (2016): 106-40.

Hsiang, Solomon, and Robert E. Kopp. An economist's guide to climate change science. Journal of Economic Perspectives 32, no. 4 (2018): 3-32.

Two additional papers

1. Burgess, Robin, Olivier Deschenes, Dave Donaldson, and Michael Greenstone. Weather, climate change and death in India. University of Chicago (2017).

2. Barreca, Alan, Karen Clay, Olivier Deschenes, Michael Greenstone, and Joseph S. Shapiro. Adapting to climate change: The remarkable decline in the US temperature-mortality relationship over the twentieth century. Journal of Political Economy 124, no. 1 (2016): 105-159.

Thank you!