The Energy Transition and Climate Change

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Economics of Energy, Climate Change, and Sustainability Program

Barcelona School of Economics

This module

- We will discuss methodologies to **quantify the impacts** of climate change.
- You will learn how some of the studies are performed by looking at the **repository code and data from a recent paper** (reading for next class).

Today

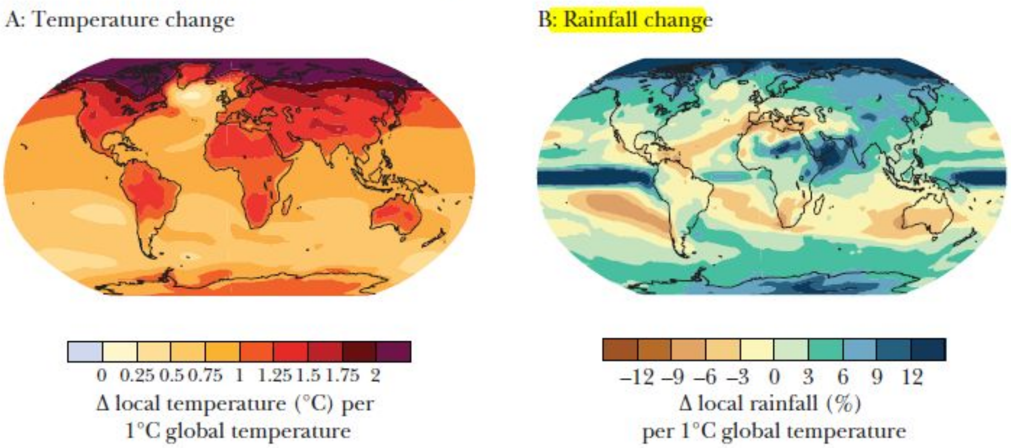
- Understand difference between carbon budgets vs. social cost of carbon
- Overview on methodologies to quantify climate damages (SCC)
- Discussion on differences between approaches and limitations

The impacts of climate change

We associate climate change with global warming

- Impacts of **temperature and rainfall.**
- Impacts on many other dimensions of the **natural environment**.
- Impacts on many aspects of **human society**.

Projected Change in Local Average Temperatures and Local Average Rainfall per 1°C of Warming in Global Mean Temperatures



Source: Collins, Knutti, et al. (2013).
Note: Changes are differences in means between 1986–2005 and 2081–2100 in CMIP5 simulations of RCP 4.5, scaled by the overall change in global mean temperature. These heatmaps should be viewed in color. See the electronic versions on the JEP website.

Other direct impacts (beyond temp + precipitation)

- **Tropical Cyclones:** driven by the temperature difference between the warm ocean surface and cooler temperatures higher in the atmosphere
- **Sea-level rise:** through an increase in the volume of water at higher temperatures and an increase in water driven by the melting of ice
- **Droughts and floods:** by altering temperature and precipitations patterns, climate change alters the frequency of extreme events (however, difficult to attribute it to human activity, although the evidence is growing)
- **Ocean acidification:** by increasing the concentration of CO2, altering marine ecosystems
- **Ecosystems:** species migrations, threatened coral reefs,...
- **Tipping points:** Nonlinearities and feedbacks can shift states once critical thresholds are crossed.

Derived impacts to human society

- **Mortality**: heat and cold deaths, viruses, bacteria.
- **Agriculture**: risks to agricultural yields due to extreme temperatures and biodiversity loss.
- **Labor**: labor supply effects due to increased hardship in extreme heat
- **Conflict**: large-scale violent conflict.
- **Crime**: interpersonal violent crime, which has been show to increase even with just temperature effects.
- **Migration**: international and within-country due to extreme temperatures, floods, etc.
- …

Measuring the impacts of climate change

- The impacts of climate change **cannot be measured**.
- We are entering an era of *unprecedented* climate, and therefore we have no past observations that can inform the future.
- Yet, important to attempt some quantification to avoid the trap:
  - **no quantification = no impact (!!!)**

- Scientists make **projections about the direct impacts** of climate change (with *high precision*).
- Economists and other social scientists **try to quantify** its economic/societal impact (with *high uncertainty*).

This is by definition an “out-of-sample” exercise that is subject to many assumptions, so we need to keep it in mind.

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Frameworks about the costs of emissions: carbon budget vs. SCC

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The costs of emissions

- GHGs have negative impacts on society that are not internalized by those who produce the emissions.
    - This is called an **externality**.

- In an ideal world, we should discourage the emissions of GHGs much more and price fossil fuels and other climate-change contributors much higher.
    - This would lead households and firms to **internalize** the costs of emissions.

- While some countries already price emissions (more later in the class), most GHGs remain *underpriced or unpriced*.

Setting the price of carbon

- A key part of economics has been concerned with what the right “price” or “cost” should be for the climate externality.
- Academic studies have been deriving both theoretical and empirical estimates of what the “optimal carbon price path” should be.
  - Examples:
    - Nordhaus, William D. "An optimal transition path for slowing climate change." Science 20 (1992): 1315-1319.
    - Golosov, Mikhail, John Hassler, Per Krusell, and Aleh Tsyvinski. "Optimal taxes on fossil fuel in general equilibrium."
- To decide the right price, one needs to know the **costs and damages**.

Setting the price of carbon (dynamic framework)

$$max_{e,a} \sum_t [V(e_t, a_t) - C(E_t)] e^{-rt}$$

- Choose:
  - Emissions at each period (e) and
  - Abatement (a – technologies to reduce emissions: green investments, energy efficiency, etc.)
    - Note: consumption/GDP is a function of these two choices.
- Take into account the per-period cost of <u>cumulative</u> emissions E at each point in time t.
- Make a choice about discounting, which can greatly impact the emissions path.
- Obtain the price that is consistent with the optimal path of emissions.

<u>Note</u>: in practice, other assumptions needed, e.g., regarding population trends.

A challenge

$$max_{e,a} \sum_t [V(e_t, a_t) - C(E_t)] e^{-rt}$$

- Many of the elements into this equation are unknown.
- Some also entail a moral judgement.
- Need to make many assumptions to get the right level of “optimal emissions” and how costly it is to achieve them to get at the “right” cost of carbon.

Example 1: we may increase the damages if we believe that it will be easy to reduce emissions in the future (e.g., in the way we model abatement), but at the end it is not.

Example 2: the shape and level of C really matter.

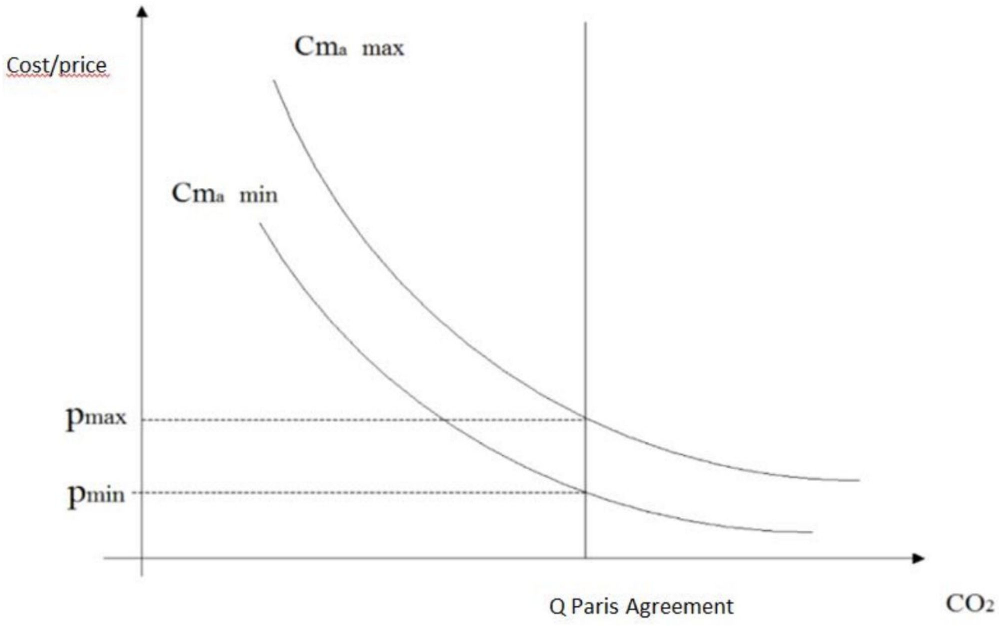
Two benchmarks to calculate the cost of carbon

- **Carbon budget and shadow cost**
  - Focuses on how to reach a certain target.
  - Gives up on computing damages with precision and focuses on the cost of the transition: optimal mitigation portfolio.

- **Social cost of carbon**
  - Focuses on getting the right curve for damages, and tries to calculate them at some “equilibrium” level (ideally, where the two lines cross).
  - Does not guarantee a particular emissions target.

Setting the price of carbon: shadow cost

Figure 7 – Cost-effectiveness approach



Source: France Stratégie

What is the shadow cost of carbon?

$$max_{e,a} \sum_t [V(e_t, a_t) - C(E_t)]e^{-rt}$$

$$\text{s.t} \quad E_T = Cap$$

- The derivative on the constraint gives us the shadow value of the emissions cap.
- Assumptions on how technology evolves (e.g., innovation) and how $CO2$ accumulates dictates the path of the implied shadow value.
  - Intermediate objectives can also be included (e.g., **2030 goals**).
- **Hotelling rule** determines the path of shadow prices.

- **Cost and innovation assumptions** are the drivers of uncertainty.

Interpretation and use of shadow cost of carbon

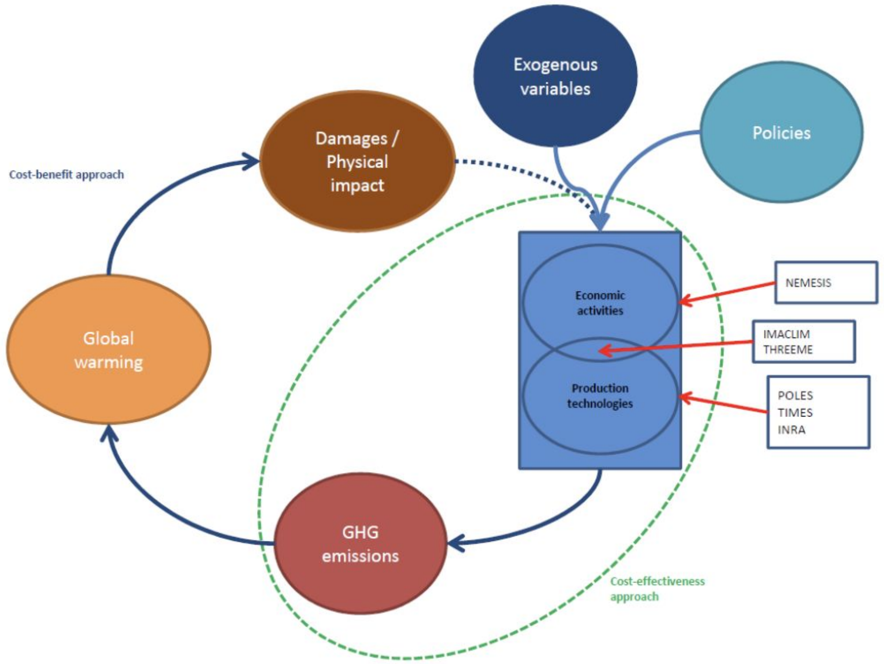
- The calculation of the shadow cost of carbon focuses on demand and technology: how to reach a certain reduction in the best way possible.

- One **perfect-markets interpretation**:
  - What carbon price do we need to set for reductions to achieve a certain target.
- An **alternative interpretation**:
  - Consider a battery of potential climate policies.
  - Once the best feasible policy portfolio is determined (or a range of policies), the marginal cost of implementing the policies is computed.
  - Cost-effectiveness.

The Quinet report: approach

- Focus on detailed modeling of production frontier and technologies in France given a carbon budget.
- Compute the **cost-effective mix of decarbonization** policies and its implied **shadow cost**.
- Focus on technological and macroeconomic model.

Figure 14 – Diagram of modeling



Source: France Stratégie, authors' representation

The Quinet report: ingredients

1. French **commitments** and carbon budgets.
2. **Technological assumptions** and techno-*economic* forecasts.
   - With constraints on the replacement of capital, need to use CGE models.
3. Literature surrounding "*sharing of the burden*"
   - To determine alternatives to the "Hotelling rule"
4. Expert and stakeholder inputs.

- These are all used in a mathematical model that determines the least-cost option to maintain the budget (cost-effective strategies).

The Quinet report: results

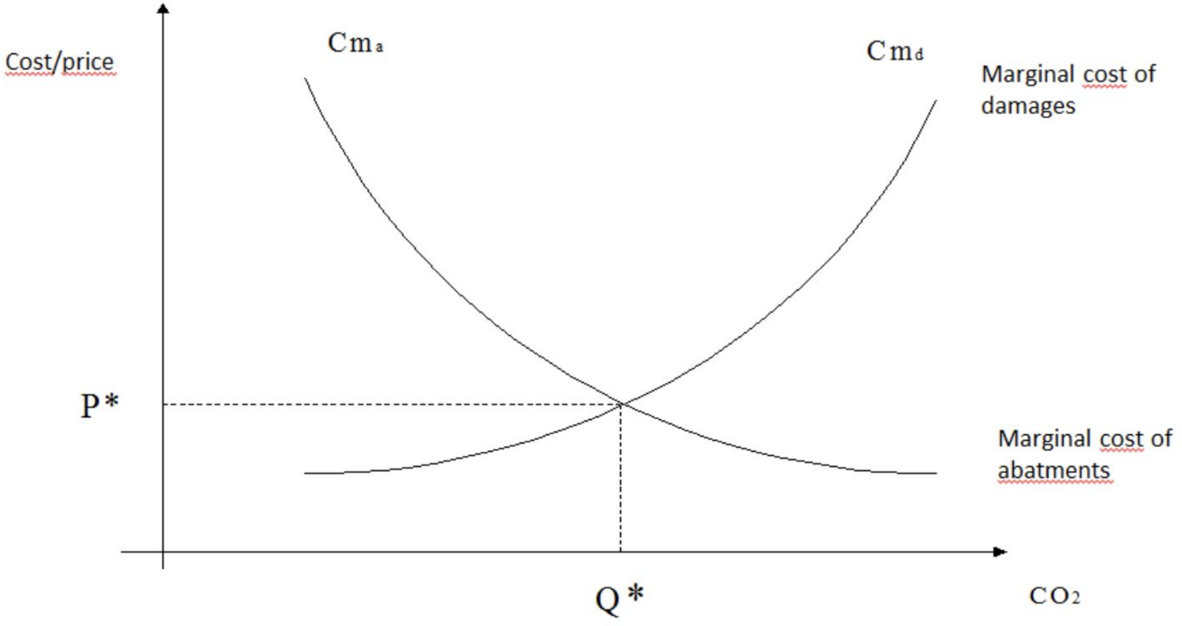
	Boiteux (2001)	Quinet 1 (2009)	Quinet 2 (2019)
2010	32	32	
2020	43	56	69
2030	58	100	250
2050	104	250	775

Source: France Stratégie. Shadow carbon price (in 2018 euros per metric ton of CO2) in France implied by three different commissions.

https://www.strategie.gouv.fr/sites/strategie.gouv.fr/files/atoms/files/fs-the-value-for-climate-action-final-web.pdf

Setting the price of carbon: social cost of carbon

Figure 6 – Cost-benefit approach



Source: France Stratégie

What is the social cost of carbon (SCC)?

Definition

The social cost of carbon (SCC) is the the monetary value of the damages from emitting an incremental ton of CO2 into the atmosphere.

In principle, it should reflect the full cost to society of the impacts associated with a warming world, including through:

- Human health
- Agricultural and labor productivity
- Property damage from increased flood risk
- Ecosystem services

The SCC includes both **direct damages and the costs of adaptation**.

Interpretation and use of SCC

To **economists**, the SCC is exactly the negative externality associated with emitting 1 ton of CO_2 during production (the shape of the externality costs).

To **policymakers**, the SCC is a critical input for developing effective and efficient climate policies.

- It facilitates efficient carbon pricing, particularly a carbon tax.
- It can be fed directly into cost-benefit analysis of regulatory actions to limit GHG emissions, e.g., to quantify the benefits of a policy reducing emissions.

Comparison of frameworks

- The **cost-benefit approach (social cost of carbon)** assumes that you can estimate and discount damage flows resulting from global warming, based on hypotheses of atmospheric concentration of GHGs and temperature rises.
  - Controversies surrounding sensitivity to discount factor (Stern Report), difficulties in predicting damages, etc.

- The **cost-effectiveness approach (shadow cost)** requires determination of a target emissions scenario.
  - One difficulty lies in modelling learning curves on technologies and hypotheses on future innovations. Easy to make the shadow cost low with optimistic assumptions (e.g., negative emissions technologies or carbon sinks).

What framework do different countries use?

- Stark differences in **approach** to climate policy: Europe vs. US
  - **EU**: Explicit physical climate goals.
  - **USA**: Focused on SCC at federal level.

- Important differences in terms of uncertainties:
  - **Climate goals**: what price in $/CO2 will keep us within budget?
  - **SCC**: what are the marginal damages in $/CO2?

Measuring the impacts of emissions (SCC)

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The challenge

$$\frac{\partial(\$\text{ of damages})}{\partial(\text{tons of }CO_2)} = \frac{\partial(\$\text{ of damages})}{\partial(^\circ C\text{ of warming})} \times \frac{\partial(^\circ C\text{ of warming})}{\partial(\text{tons of }CO_2)}$$

- (Relatively) High certainty on the **evolution of warming** as a function of CO2 (at least within acceptable range, some models include tipping points).
- High uncertainty on the **cost of warming** – this is where economists come in…

Note: traditional focus is on temperature, as a proxy for all effects, although work has been extended to cover other damages.

Methodologies

- The calculation of the SCC follows the tradition of using integrated assessment models to understand impact of emissions on the economy (**economic damages** in $/ton).
- Steps:
  - Modeling impacts of temperature in a model of the economy based on some assumptions but little data with **IAMs**.
  - Using past data to improve upon these numbers, without having a full economy model with **regressions** (more on this with Jacint), and then incorporating them into a SCC calculation.

IAMs

IAMs combine climate processes, economic growth, and feedbacks between the two into a single model.

- Specifically, they translate changes in CO2 emissions into economic damages.
- Examples: FUND, DICE, PAGE (more on this with Prof. Marti Mestieri).

Benefits:

- They answer “everything.”

Costs:

- Highly dependent on validity of assumptions.

IAM ingredients

- **Socioeconomic and emissions trajectories**
  - Based on ensemble IAM predictions
- **Equilibrium climate sensitivity**
  - long-term increase in annual global- average surface temperature due to a doubling of CO2 concentrations relative to pre-industrial levels
- **Discount rates**
  - Typical range, 1%-3%.
- **Global or domestic damages**
  - Usually consider global damages, i.e., the model includes all countries.
  - Usually no extra protection regarding low-income countries, even though it can be justified based on marginal utility of income and environmental justice concerns.

Getting the derivative

For each **IAM x socioeconomic scenario x discount rate** (e.g., 45 total in US calculation):

1. Input future **total emissions, GDP, and population**; and calculate temperature-effects and consumption-equivalent damages for each year.
2. **Add 1 unit of CO2** in period t, recalculate total damages by year.
3. **Subtract damages** in step 1 from those in step 2 to obtain marginal damages
4. **Sum marginal damages across years**, discounting by agreed rate

Lastly, average across (IAM x socioeconomic scenario) to obtain one period-t SCC distribution per discount rate.

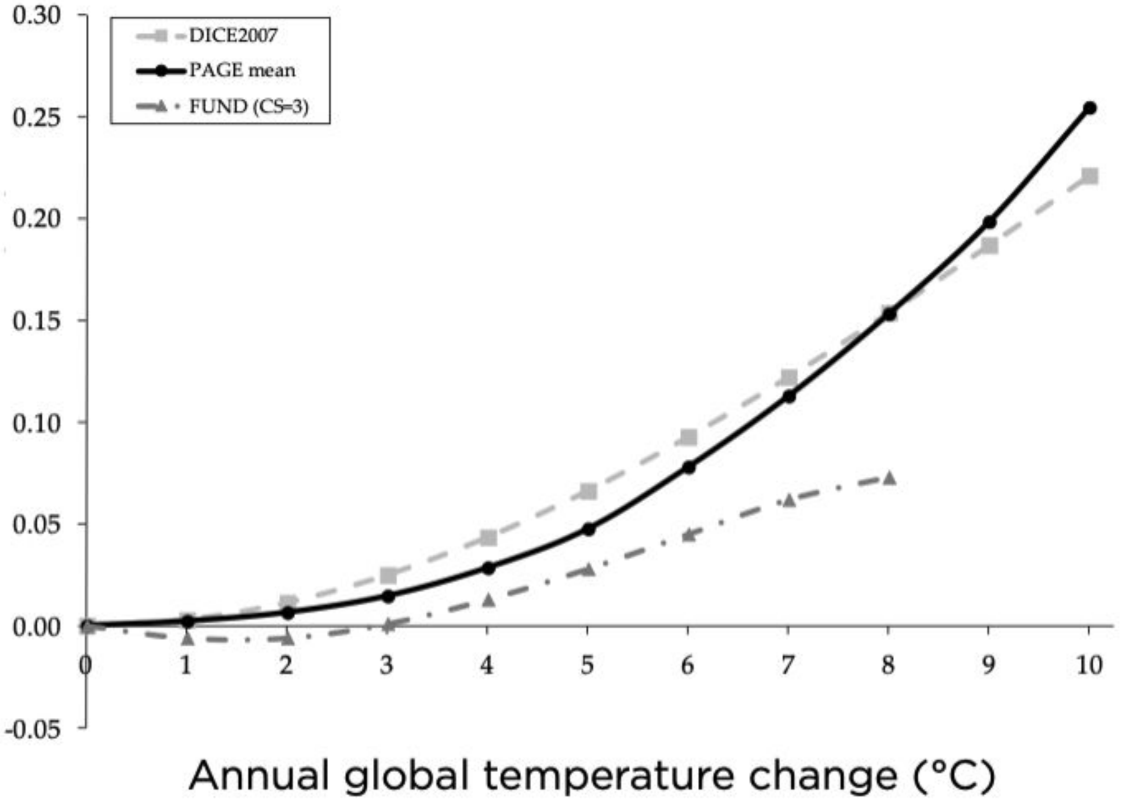
Historical damages from IAMs have been low

Embarrassingly (?) low.

Leads to low social costs of carbon.

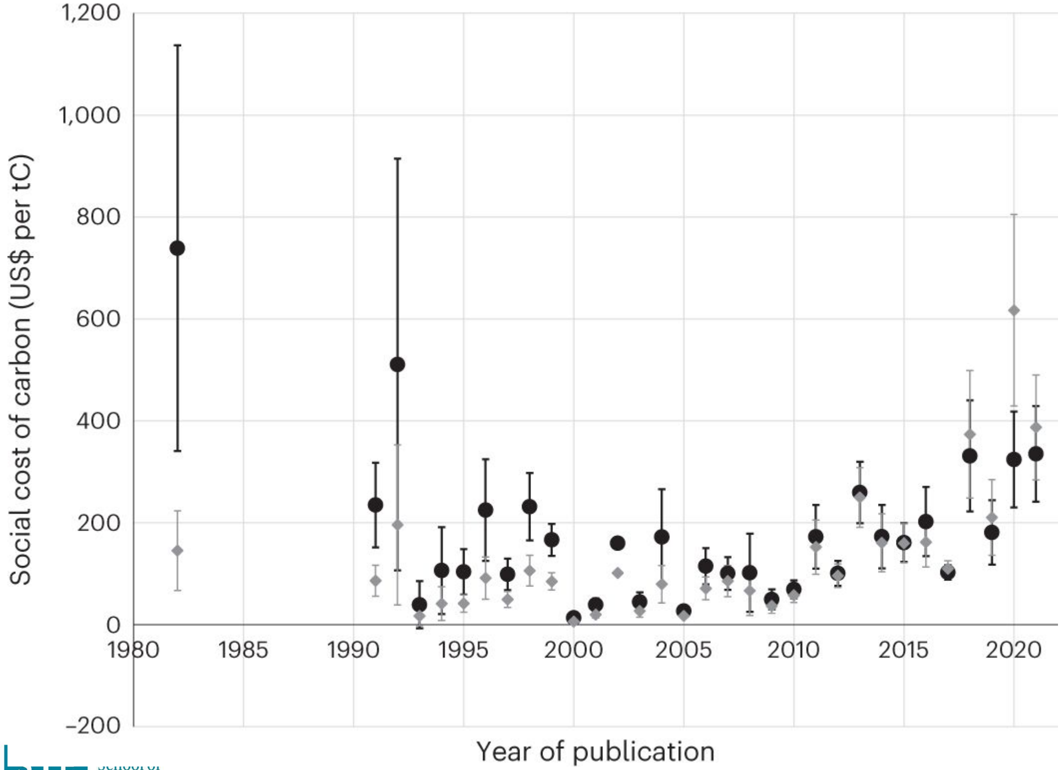
E.g., original EPA estimates less than $20-30/ton.

You will see how these models are built in Macro I.

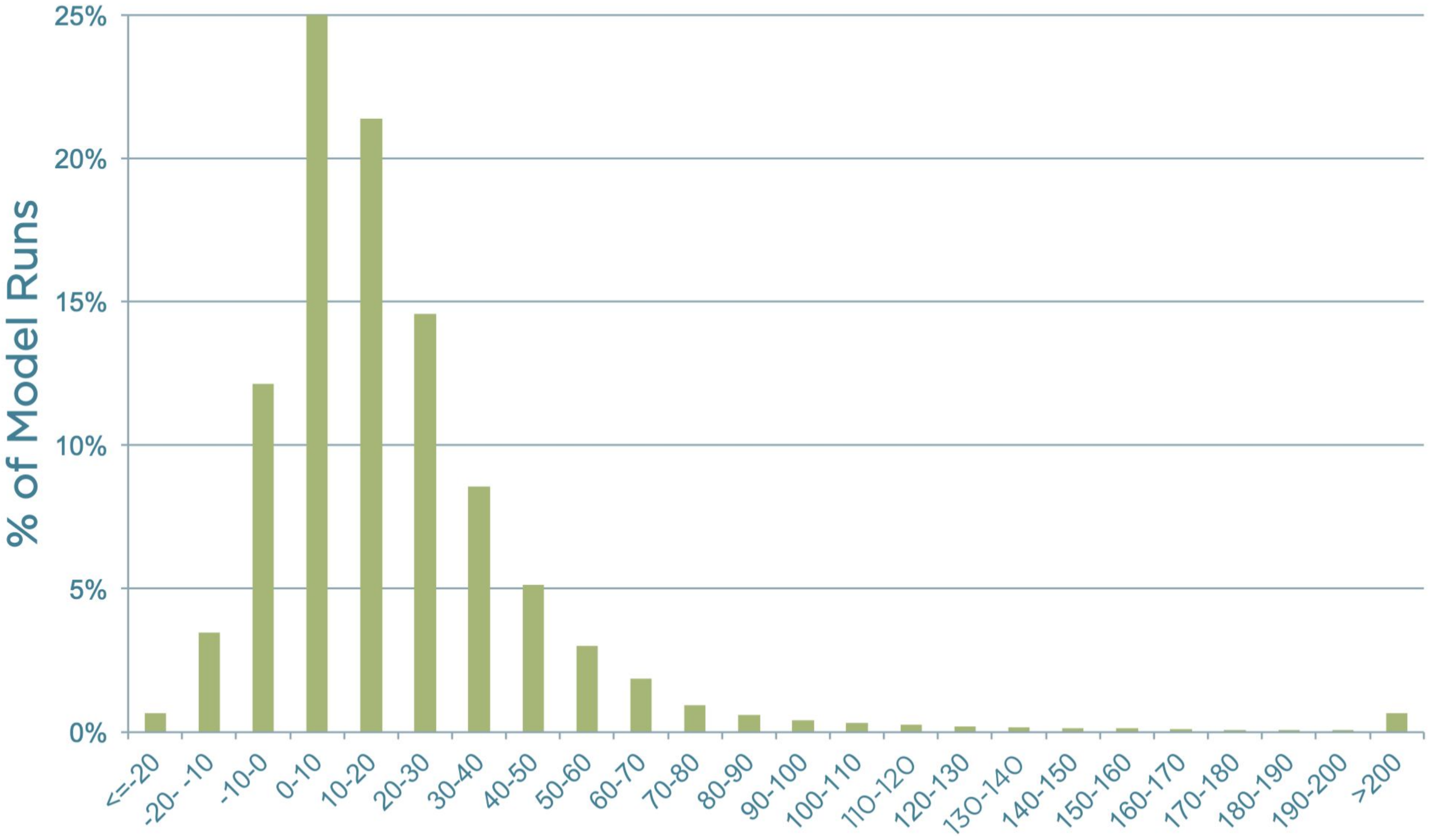


Estimates have been steadily increasing

See Tol (2023), dataset and code for paper also provided.



US-EPA estimates original study at 3% discount



US-EPA estimates (2016 update)

	Discount Rate and Statistic			
Year	**5% Average**	**3% Average**	**2.5% Average**	**High Impact (95th pct at 3%)**
2015	$11	**$36**	$56	$105
2020	$12	**$42**	$62	$123
2025	$14	**$46**	$68	$138
2030	$16	**$50**	$73	$152
2035	$18	**$55**	$78	$168

https://19january2017snapshot.epa.gov/climatechange/social-cost-carbon_.html

US–EPA estimates (latest report)

Table ES.1: Estimates of the Social Cost of Greenhouse Gases (SC-GHG), 2020-2080 (2020 dollars)

	SC-GHG and Near-term Ramsey Discount Rate								
	SC-CO_2 (*2020 dollars per metric ton of CO_2*)			SC-CH_4 (*2020 dollars per metric ton of CH_4*)			SC-N_2O (*2020 dollars per metric ton of N_2O*)		
Emission	Near-term rate			Near-term rate			Near-term rate		
Year	2.5%	2.0%	1.5%	2.5%	2.0%	1.5%	2.5%	2.0%	1.5%
2020	120	190	340	1,300	1,600	2,300	35,000	54,000	87,000
2030	140	230	380	1,900	2,400	3,200	45,000	66,000	100,000
2040	170	270	430	2,700	3,300	4,200	55,000	79,000	120,000
2050	200	310	480	3,500	4,200	5,300	66,000	93,000	140,000
2060	230	350	530	4,300	5,100	6,300	76,000	110,000	150,000
2070	260	380	570	5,000	5,900	7,200	85,000	120,000	170,000
2080	280	410	600	5,800	6,800	8,200	95,000	130,000	180,000

Values of SC-CO_2, SC-CH_4, and SC-N_2O are rounded to two significant figures. The annual unrounded estimates are available in Appendix A.5 and at: https://www.epa.gov/environmental-economics/scghg.

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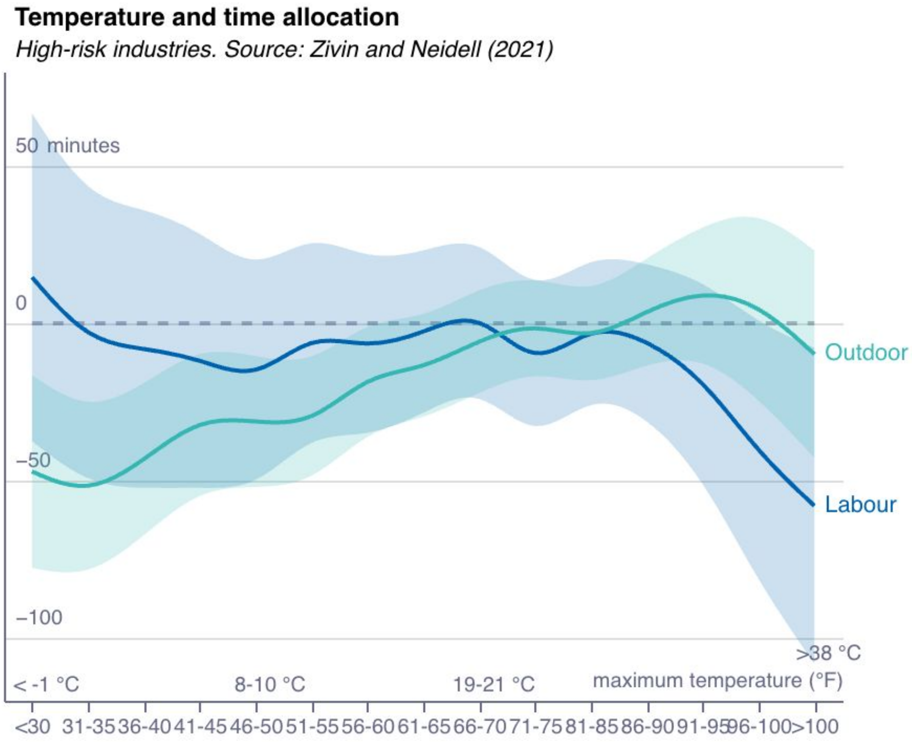
Using regressions to improve the SCC

- Using regressions to understand mortality impacts with detailed microdata.
  - Example: Idea is to look at what happens in heat waves, but also at “hotter places”.
  - Hotter places are already adapted to extreme weather, which is considered a prediction on “adaptation” within this literature.
- A big emphasis in this literature is to discuss to which extent one can learn from such an exercise, which is not 100% obvious.

Regressions: an example from the literature

- Workers in industries that are regularly exposed to the heat (agriculture, landscaping, and construction) reduce the number of hours when daily maximum temperatures exceed 32°C.
- One can translate hours worked into quantifiable economic impacts, but just capturing *partial effects*.
- On a more positive note, papers find evidence of adaptation (e.g., comparing states with traditionally high temperatures).



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A big effort, although intrinsically a difficult task

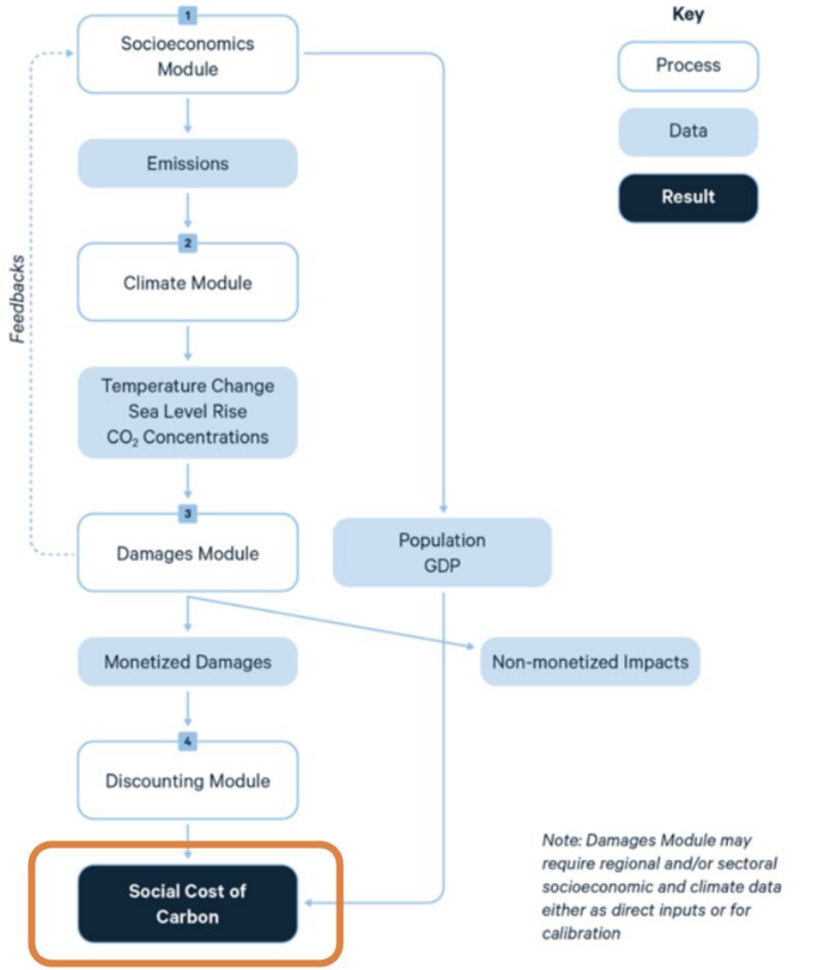
- Several teams try to quantify the economic impact of climate change using data.
- Typically focused on **mortality, morbidity, and labor productivity**, as these are most easily quantified. Also **economic losses to infrastructure** (sea level rise).
- See work by a leading team: https://impactlab.org/
- See their model integrating regression estimates with the calculation of the SCC (US EPA) at: https://github.com/ClimateImpactLab/dscim-epa

- These large models generate science-based estimates of the damages from climate change.
- They are *not perfect*, but they can successfully impact policy making by offering a quantifiable effect that can be included in cost-benefit analyses.

How are regressions incorporated into IAM-SCC calculations?

- There are big efforts to improve the credibility of IAM-SCC calculations.
- Attempts to make them more transparent and comprehensive.
  - Expert feedback
  - Empirical basis for assumptions around **damages**.

https://www.nature.com/articles/s41586-022-05224-9



Source: National Academies of Sciences, Engineering, and Medicine. 2017.

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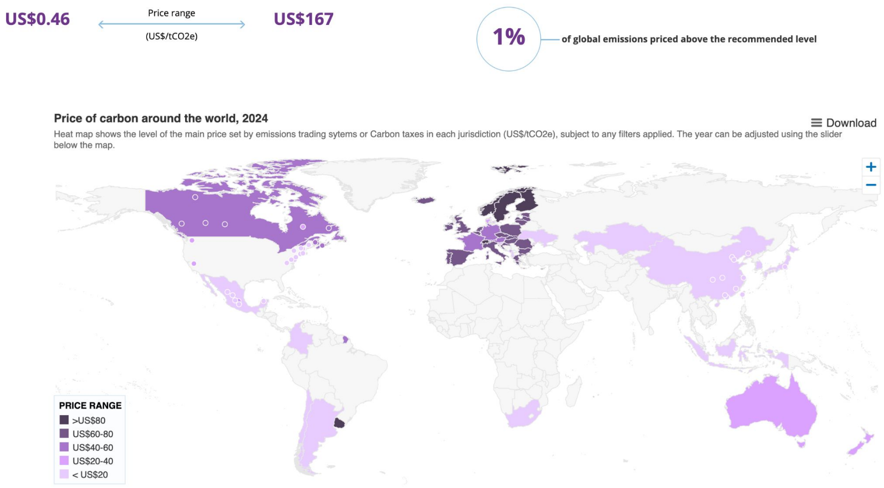
While SCC high, carbon prices are absent or low

- SCC can be used to quantify the cost-benefit of *subsidies*
- However, **emissions pathways need to be consistent with the assumptions** behind the SCC.

- Without explicit emissions targets or “stick” policies, it will be difficult to maintain assumptions behind calculations.



https://carbonpricingdashboard.worldbank.org/

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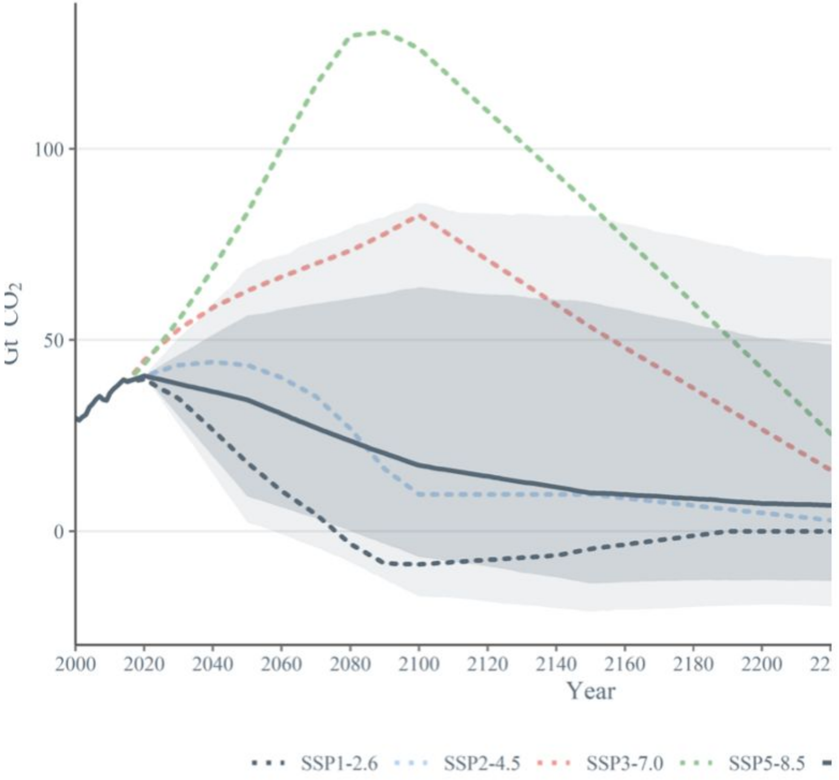
A challenge with SCC and US policy: SCC is an output, not an equilibrium input

- Expected emissions, and thus, expected temperature increases and expected damages do not depend on the SCC in the IAM-SCC calculation.
- Many of the current models do not check that, at the **recommended SCC**, the emissions path is consistent with the desired goal.
- Using very favorable IPCC scenarios leads to lower SCC, but in reality, it would require much higher CO2 prices.



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