Lecture 9: Estimating Climate Damages using the Social Cost of Carbon

Prof. Theising

Environmental Economics

Econ 4075

Climate Change and Economics

- Climate economics aims to identify the relationship between the economy/welfare and the overall environment on earth.

- But first, what do we mean by *climate*?
    - In general, we want to think about *climate* as a long-run conditions of the environment. A common window to define this is 30+ years.
    - But climate isn't just mean (average) conditions of the environment (temperature, precipitations, etc.), we think of it encompassing higher order moments of environmental conditions' distribution and more.
        - Frequency or severity of storms (think recent upticks on tropical storms, etc.), frequency and severity of draught or heat waves, ecological conditions and ocean pH, the interconnectedness of these, etc…
    - Even if these things are "on average" the same (annually, etc.) , their affect on economic outcomes could be very different.
    - Things we don't even know about yet (unknown unknowns).

Where do we want to end up?

- We've been discussing how to value benefits from the environment. Robust climate valuation is obviously trickier: impacts to the economy through many, many channels!

- What we want is a single value measure of the benefit from a marginal reduction in carbon emissions…

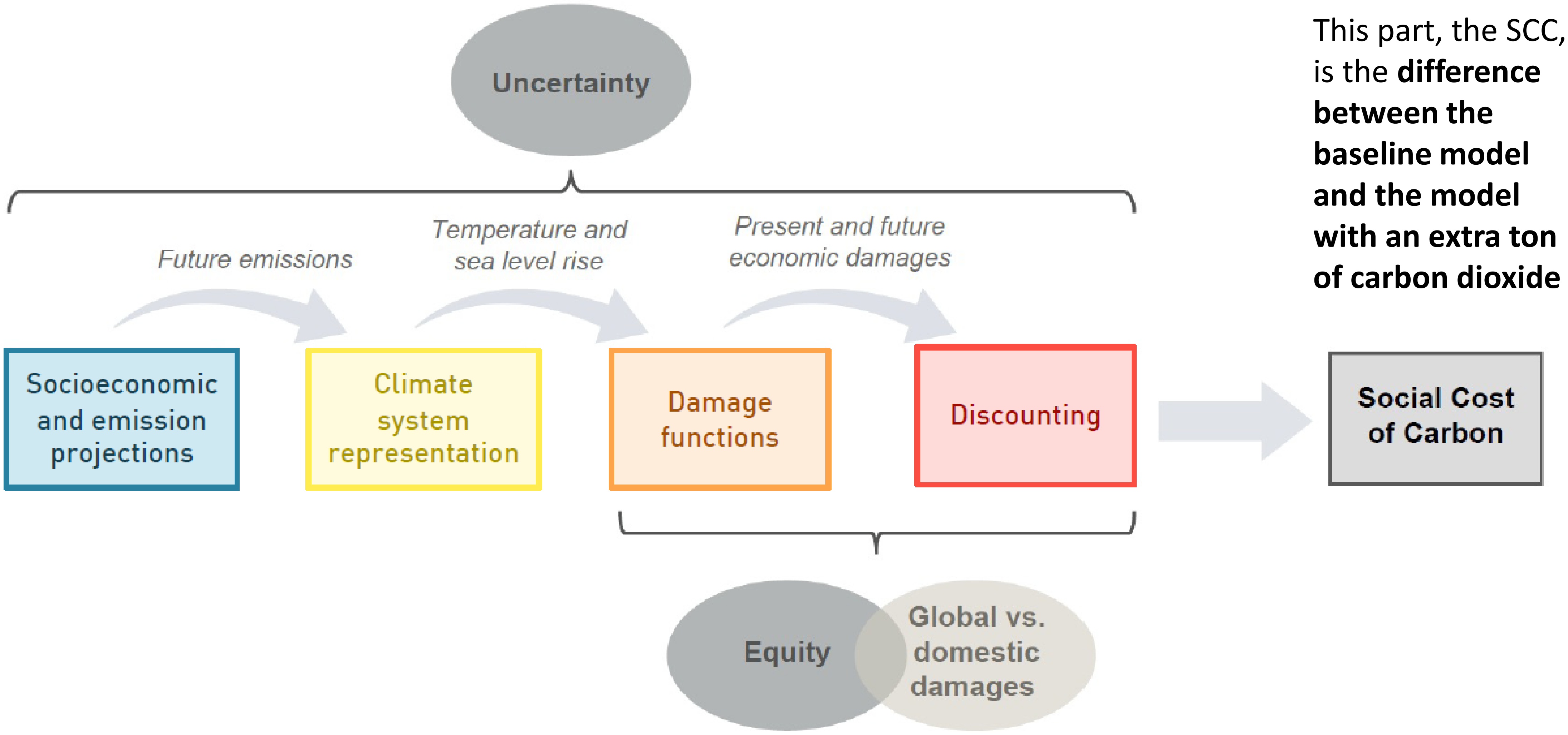
Social cost of carbon:

"an estimate, in dollars, of the economic damages that would result (now and in the future) from emitting one additional ton of carbon dioxide into the atmosphere today."

- In illustrative terms: *SCC measures the global damages to the world economy over the next 300 years from carbon you would emit while driving a Ford Mustang from SF to Chicago.*

- We typically use **integrated assessment models** to estimate the SCC
  - Can apply a similar exercise to other greenhouse gases

How to get to the SCC: a bio-macroeconomic model in 4 modules



This part, the SCC, is the **difference between the baseline model and the model with an extra ton of carbon dioxide**

Let’s work backwards, step by step…

Discounting

Discounting

In thinking about climate change, we know that many of the effects will occur in the long run.

A key question is how to compare benefits of mitigating climate effects way down the road (60+ years from now), to costs that we incur today.

Economists (and our finance/policy peers) generally use a **discount rate**: a value that tells us how much future dollars are worth in today's terms.

Discounting

Discounting

Discounting results in us placing less value on costs and benefits that accrue in the future

At an annual discount rate of *r*, a dollar today is worth *(1+r)* dollars one year from now.

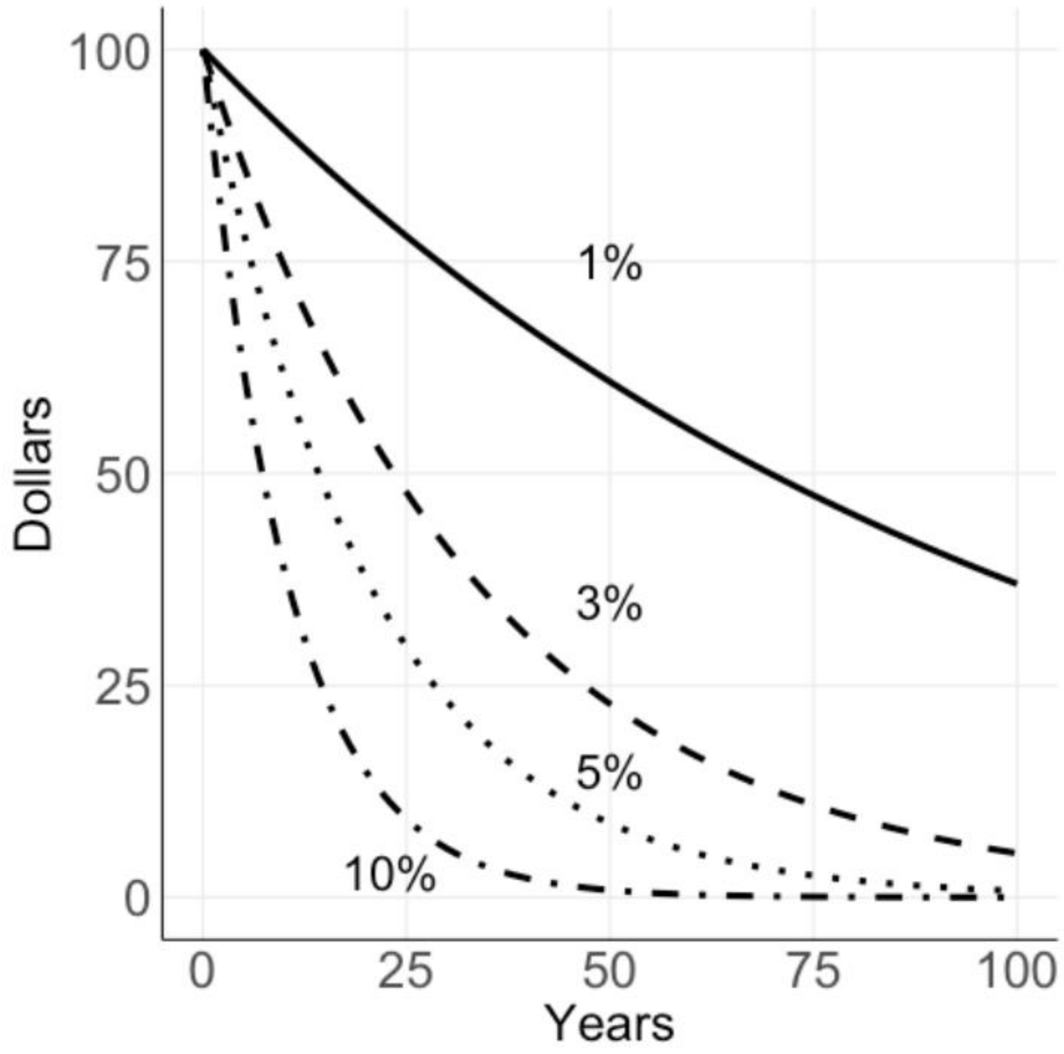
Conversely, a dollar 1 year from now is worth $\beta = \frac{1}{1+r}$ dollars today. This is known as a **discount factor**.

For a fixed discount rate, a dollar 100 years from now is worth $\beta_{100} = \left(\frac{1}{1+r}\right)^{100}$.

As we'll discuss more during Dr. Austin's lectures on BCA, the *timing* of costs and benefits resulting from potential environmental policies or projects and the *choice of discount rate* affect the implied **net present value** of the options.

Present value of $100

Discounting



Higher discount rates place less value on future benefits.

With a discount rate of 10%, $100 received 50 years in the future has basically zero present value.

Contrast with a discount rate of 1%: $100 received 100 years in the future holds roughly $40 in present value.

Let's use some larger numbers

Discounting

$1 billion in climate damages that occurs 200 years from now, when discounted at a **2% rate**, has a present value of roughly **$19 million**.

$1 billion in climate damages that occurs 200 years from now, when discounted at an **8% rate**, has a present value of roughly **$21,000.**

The punchline: this parametric "lever" is probably the most contentious number in environmental economics.

So how do we choose a discount rate?

Discounting

Option 1: take the market rate (i.e. the real interest paid on investments)

You could argue for something like the return on Treasury notes (typically seen as risk free) or corporate bonds (riskier).

Could also argue for something that more fully captures the productivity of capital investments – perhaps the long-run market return of the S&P 500.

As a regulator, however, there might be reasons we don't like this approach:

- Market rates do not reflect externalities
- Government represents *future* generations as well as current generations… only current generations are represented in the market.

So how do we choose a discount rate?

Discounting

Option 2: social discounting

We can use economic and ethical considerations to justify and determine the rate.

Why discount at all?

- We know there is a time value to money: people are impatient.
- We know that there is diminishing utility from consumption and typically expect economic growth: all else equal, if someone is richer in 10 years, a dollar is worth more to them today that in 10 years.

We use what is known as the Ramsey discounting rate to accommodate these considerations

Ramsey discounting

Discounting

Skipping a lot of math, the formula for the socially optimal discount rate is:

$$r = \delta + \eta \times g$$

δ is called the **pure rate of time preference**: it measures how much we value future utility

η is the **elasticity of marginal utility**: how quickly does marginal utility decline in consumption?

g is the **growth rate**: how fast does consumption grow over time?

Ramsey discounting

Discounting

$$r = \delta + \eta \times g$$

Put another way:

δ : how much is 1 util tomorrow worth today?

η : how much do we value consumption smoothing/inequality? Typically assumed > 0 (since diminishing MU). The larger this parameter is, the steeper diminishing returns from consumption. For instance, η=1 implies the marginal utility of an additional unit of consumption is twice as large for a person with only half the income. η=2 implies marginal utility of an additional unit is 4 times higher, and so forth…

g is the growth rate: how rich do with think future generations will be compared to today?

Ramsey discounting

Discounting

$$r = \delta + \eta \times g$$

How to pick δ? Any philosophers here?

Ramsey (1928): placing different weights upon the utility of different generations is "ethically indefensible"

Harrod (1948): pure time preference represents human weakness, that government should ignore. Discounting utility is a "polite expression for rapacity and the conquest of reason by passion"

Bauer and Eckstein (1957): People, in fact, have time-positive preferences; removing δ from the social discount rate is more authoritarian than ethical

Ramsey discounting

Discounting

$$r = \delta + \eta \times g$$

Choosing η also conveys an ethical choice: how do we weigh consumption across generations

If η = 0, consumption in future doesn't change our willingness to save/invest today.

If η > 0 and g>0, we are **less likely** to invest in the future (e.g. future generations will be rich anyway)

If η > 0 and g<0, we are **more likely** to invest in the future (e.g. future generations will be poorer than today)

Ramsey discounting

Discounting

In sum, more egalitarian discounting perspectives yield…

a smaller δ (and a smaller r) **with respect to time preference.**

a larger η (and a larger r, assuming g>0) **with respect to intergenerational inequality aversion.**

Where does this leave us?

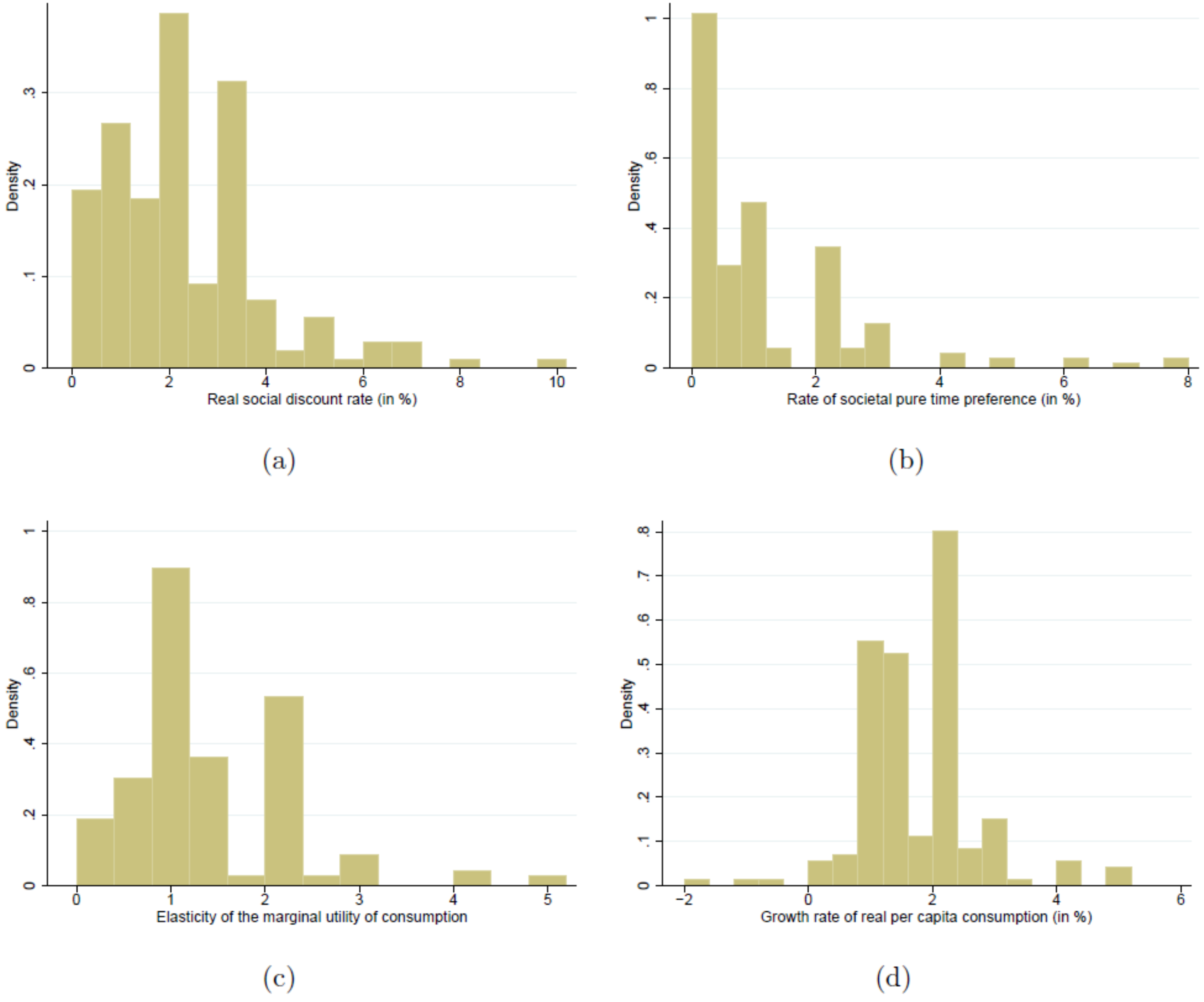
Typically, a discount rate somewhere between 1% and 7%.

(As of early 2023, the White House had proposed using a 1.7% social discount rate.)

What do the experts think?

Discounting

From Drupp et al. (2018): “Discounting Disentangled”, *AEJ:EP*



Calculating Economic Damages from Climate Change

Damage functions

So we've thought a bit about how to discount future damages.

Our next step, working backwards, is to produce estimates of damages over time.

To do this, we need to translate long-run changes in the climate into measures of economic damages.

Broadly speaking, there are two ways of getting at this: a **top-down** approach, or **bottom-up / sectoral** approach.

Top-down approaches to measuring economic damages

Damage functions

Top-down studies attempt to directly estimate the effect of climate change on aggregate outcomes like GDP

Empirical work estimating these damage functions typically use previous short-term variations in *weather* over space to identify how GDP responds to a distribution of temperature.

The idea is that this estimated relationship can then be used to project how the aggregate economy performs in the future as it is exposed to a different distribution of weather/climate.

Top-down approaches to measuring economic damages

Damage functions

Advantages:

- Easy to plug-and-play with existing macroeconomic models that rely on these aggregate measure but lack climate effects
- Top-down approach theoretically captures all sector impacts **and feedbacks/interactions between them**

Top-down approaches to measuring economic damages

Damage functions

Disadvantages?

Top-down approaches to measuring economic damages

Damage functions

Disadvantages:

These approaches miss slow-moving damage channels like sea-level rise and ocean acidification. They cannot be empirically identified, and/or data might not yet exist.

These approaches may struggle to account for **adaptation** (foreseen, or not), and projections based on their damage functions could be biased (most likely upward)

These approaches are based on historical data, requiring projections **out of sample** and/or strong functional form assumptions on the damage function

These approaches rely on GDP as a welfare measure, and might miss crucial climate impacts like human health, accumulated wealth, or migration.

Bottom-up approaches to measuring economic damages

Damage functions

Instead of looking at aggregate GDP impacts directly, we can focus on **carefully identifying the empirical impacts of climate on specific economic sectors or categories of damages**.

This is exercise wonderfully useful because we can:

(a) Aggregate up sectoral climate damages into a total impact to GDP, and
(b) Use what we learn about expected sectoral impacts for planning, vulnerability assessment and adaptation.

Because we are doing this bottom-up, we can use different methodological/econometric/ statistical approaches to identifying separate climate impacts; i.e. use the best tool to measure the impact of climate change on an individual economic channel.

This is still a hard problem… why?

The ideal experiment for measuring climate damages

Damage functions

- Randomized Control Trials (RCTs) are the gold standard for identifying causal relationships. What would an experiment (RCT) look like in the case of estimating the causal relationship between climate and the economy?
- Ideal: Many earths, where we can pump a varying amount of carbon dioxide into the atmosphere to change the climate. Examine the differences between the treatment and control earths over the next several hundred years.
- What we have: One earth and some quasi-experimental econometrics methods that identify model parameters from variation in historical observation (either cross-sectional or panel).

Where we stand in terms of sectoral/categorical climate impacts (circa-2020)

Damage functions

Table 1

Coverage of the Damage Function Literature

Sector	*Plausibly causal estimates*	*Adaptation addressed*	*Global coverage*	*Examples*
Agriculture	Yes	Yes	Yes	Schlenker and Roberts (2009); Moore, Baldos, Hertel, and Diaz (2017)
Forestry	No	No	No	
Species loss	No	No	No	
Sea-level rise	Yes	Yes	No	Houser, Hsiang, Kopp, and Larsen (2015)
Energy	Yes	Yes	No	Auffhammer (2018)
Human amenity	Yes	~Yes	No	Albouy, Graf, Kellogg, and Wolff (2016); Baylis (2015)
Morbidity and mortality	Yes	Yes	Yes	Deschênes and Greenstone (2011); Carleton et al. (2018)
Migration	Yes	No	No	Bohra-Mishra, Oppenheimer, Hsiang (2014); Missiran and Schlenker (2017)
Crime and conflict	Yes	No	Maybe	Burke, Hsiang, and Miguel (2015b)
Productivity	Yes	No	No	Peng, Deschênes, Meng, and Zhang (2018)
Water consumption	No	No	No	
Pollution	Yes	Maybe	No	Bento, Mookerjee, and Severenini (2017)
Storms	Yes	Yes	No	Hsiang and Narita (2012); Deryugina, Kawano, and Levitt (2018)

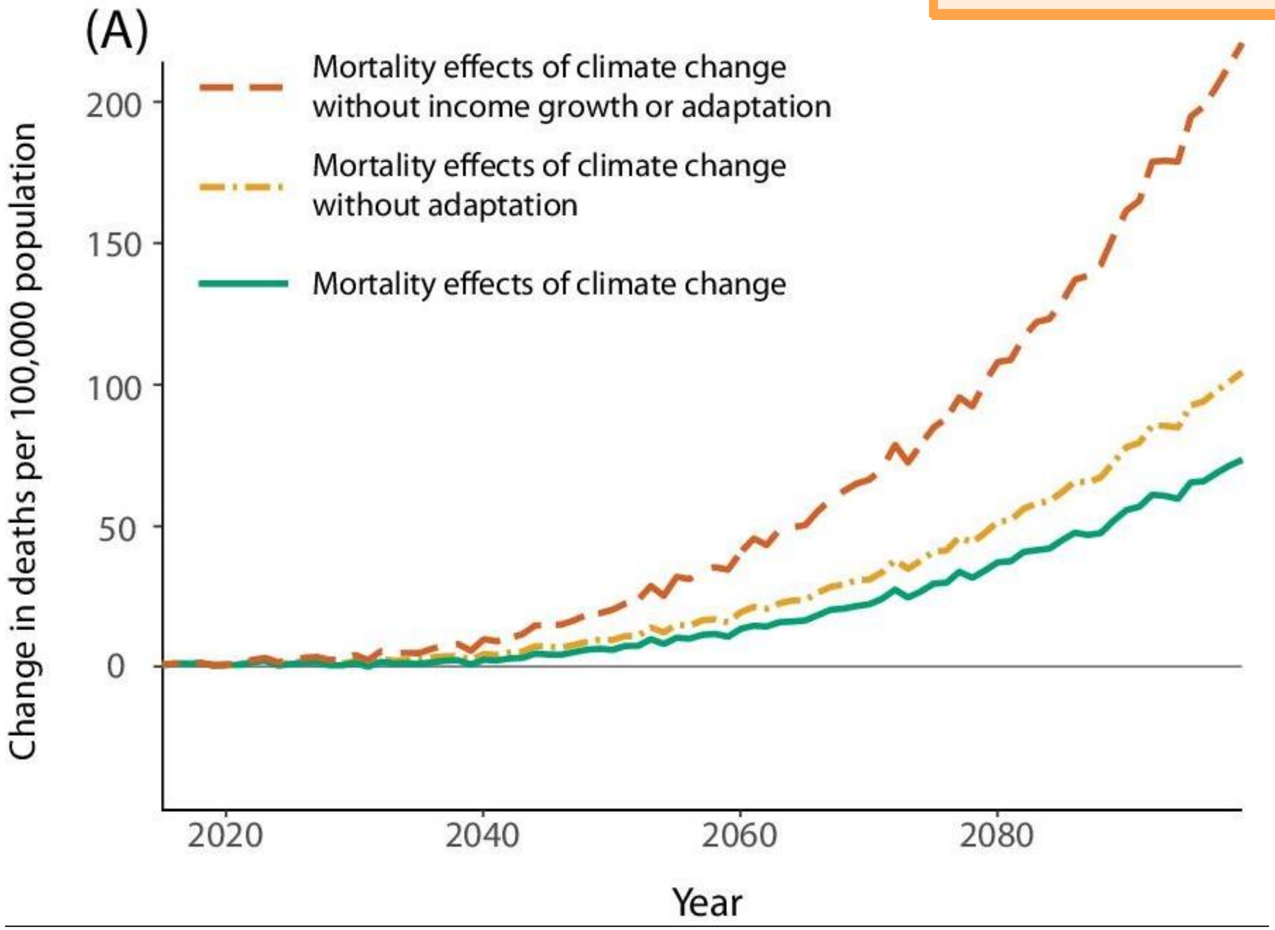
Source: Auffhammer (2018, *JEP)*

Improving on naïve climate econometrics

Damage functions

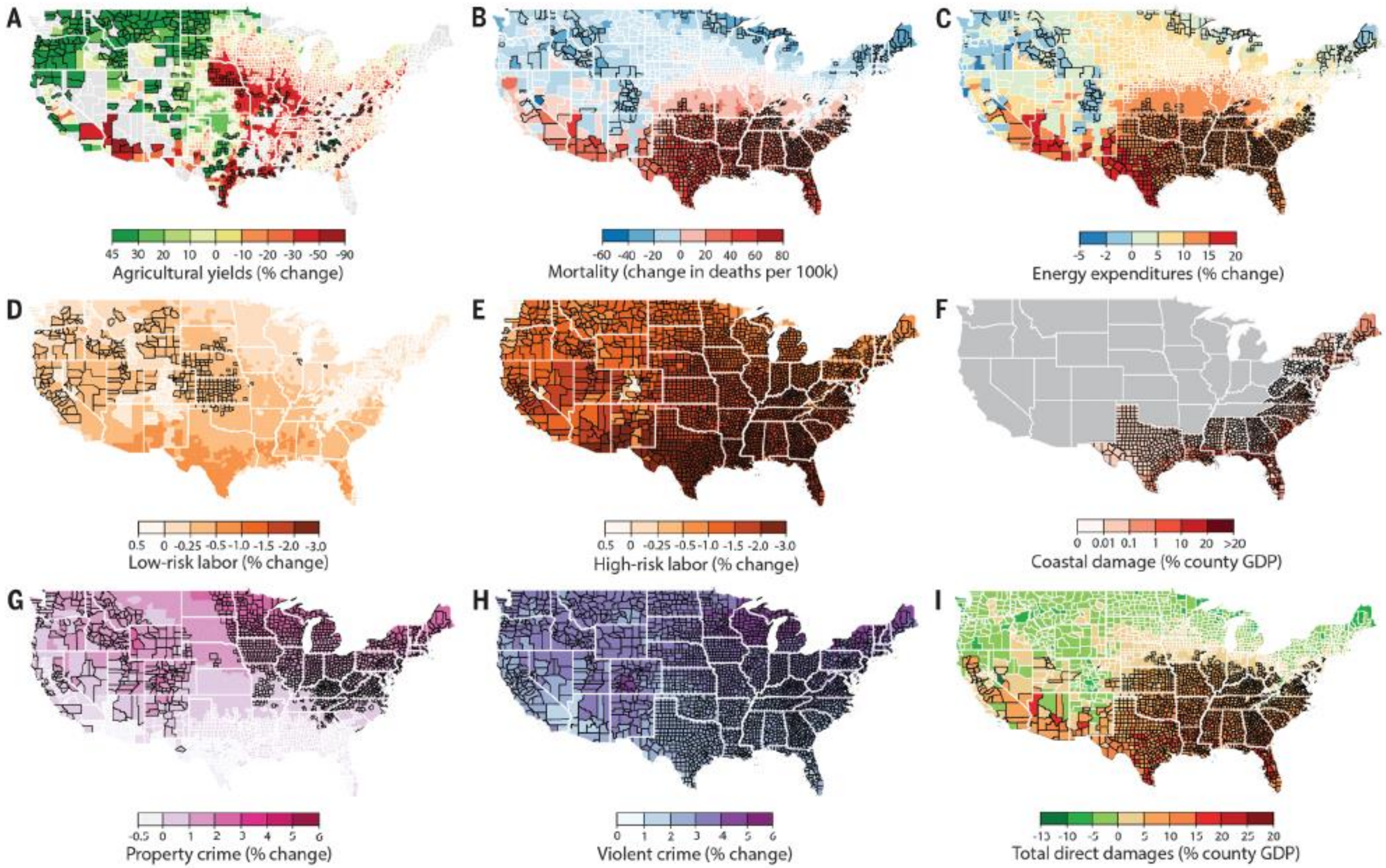
Example: What is the effect of climate on global mortality?

- Very hot and very cold temperatures are both bad for mortality, what's the overall effect of climate change?
- Difficult to account for adaptation: people will migrate, buy air conditioning, etc.
- Failing to account for adaptation will overstate the effect of climate change. See Carleton et al. 2022 for a nice empirical treatment of mortality risk adaptation.



Aggregating up to GDP from sectors…

Damage functions



Source: Hsiang et al. (2017, *Science)*

Modelling climate responses to anthropogenic activities

Climate system representation

Our next step, still working backwards, is to produce an input for our damage functions.

If we are measuring damages over time as a function of climate, we need measurements of how the climate is evolving.

These climate measurements can be simple (global mean surface temperature [GMST] is a single-attribute statistic often used for climate) or complex (including temperature, precipitation, sea level rise, ocean acidification, and more).

Climate models formally characterize the relationships between emissions (input variable, a flow) and atmospheric CO2 concentrations (a stock), and the resulting changes in climate

Many flavors exist in complete IAMs. Some currently notable climate modules: FaIR, BRICK

Forecasting future economic activity and emissions

Socioeconomic and emission projections

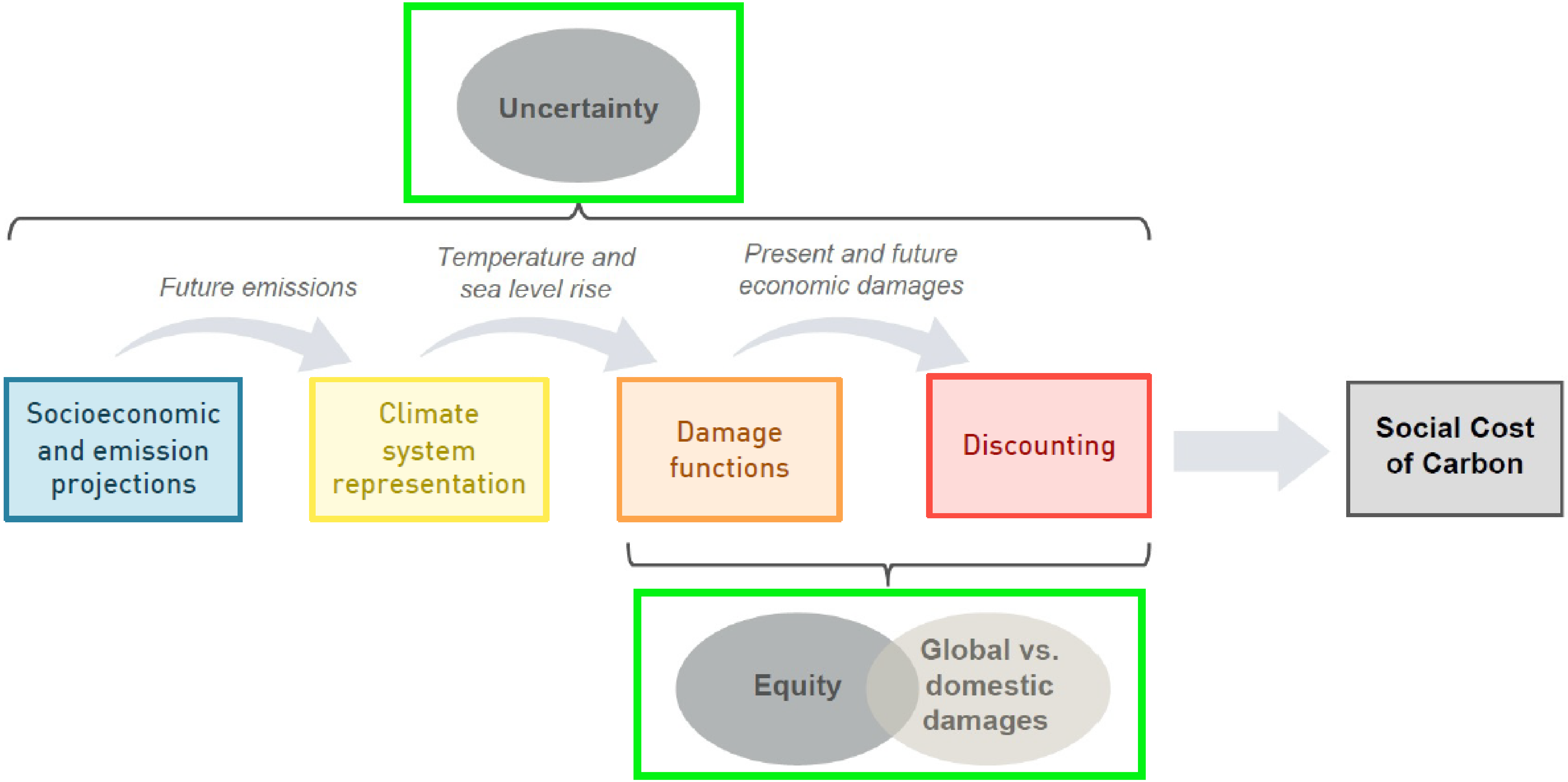
Finally, the *first* step is to produce forecasts of population, industrial economic activity, and ultimately CO2 emissions, to input into the climate module.

The socioeconomic projection module forecasts emissions based on models generated by demographers and macroeconomists.

Some of the best modelling to date tries to account for future intermediate-term policy changes and for dependencies across socioeconomic variables; it also incorporates both statistical frameworks and solicited expert judgment about the evolution of demographics and activity in the *very long run*.

We use these socioeconomic projection models to calculate CO2 emissions over time. These models could calculate emissions under "business-as-usual" or climate policy scenarios; the baseline case is often set as the former, but in some instances, it might make sense to use non-BAU climate policy scenarios as a baseline.

Additional "modules" of an IAM



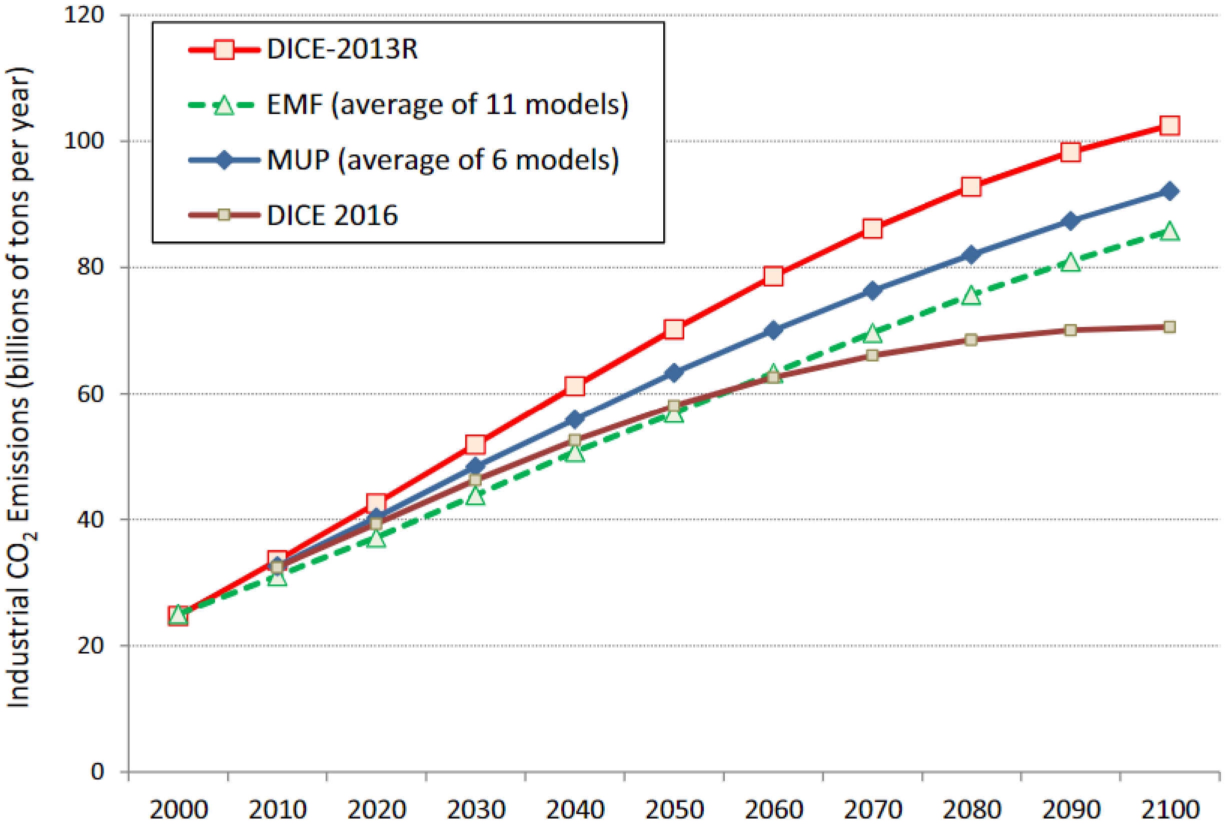
Revisiting the social cost of carbon
By: Nordhaus (2017)

- The Dynamic Integrated Assessment model of Climate and the Economy (DICE)
- Goes way back (late 1980's), still commonly used today because of its simplicity and transparency. Can be easily extended/altered to various assumptions.

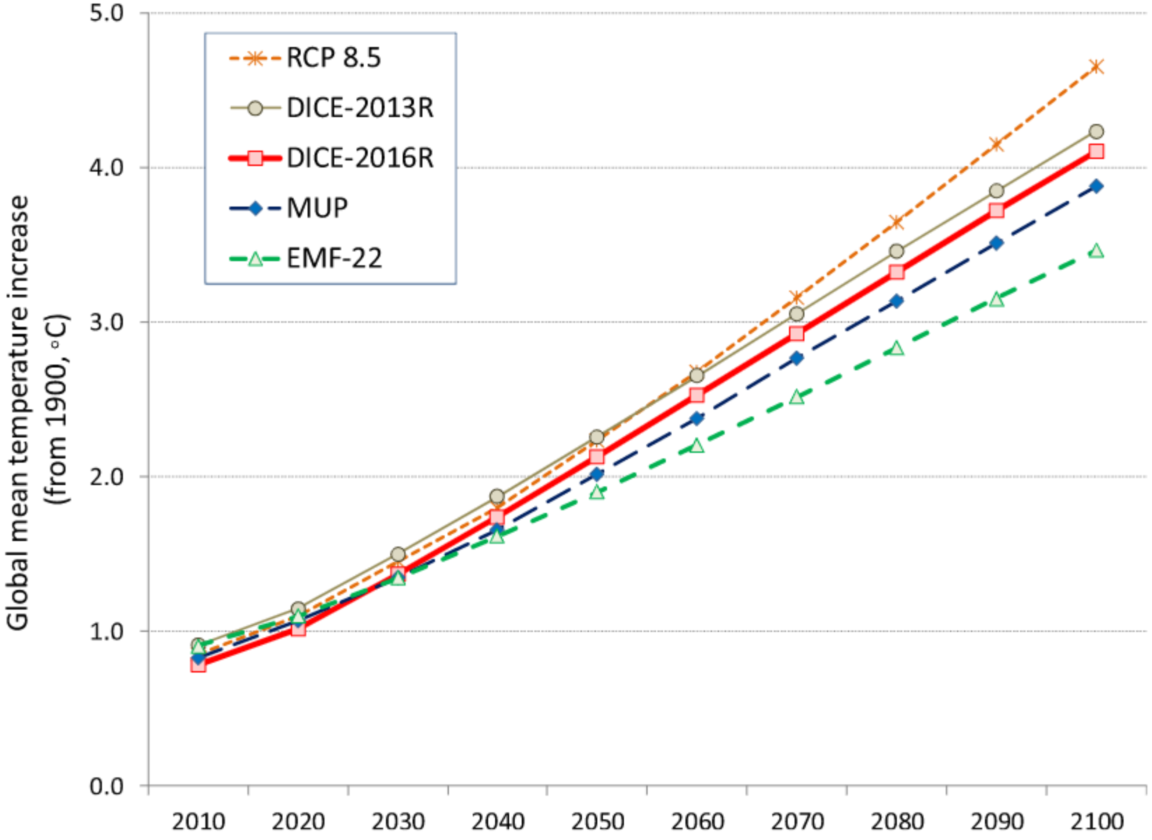
Abstract: The social cost of carbon (SCC) is a central concept for understanding and implementing climate change policies. This term represents the economic cost caused by an additional ton of carbon dioxide emissions or its equivalent. The present study presents updated estimates based on a revised DICE model (Dynamic Integrated model of Climate and the Economy). The study estimates that the SCC is \$31 per ton of CO_2 in 2010 US\$ for the current period (2015). For the central case, the real SCC grows at 3% per year over the period to 2050. The paper also compares the estimates with those from other sources.

Revisiting the social cost of carbon
By: Nordhaus (2017)

Socioeconomic and emission projections



Climate system representation



Revisiting the social cost of carbon
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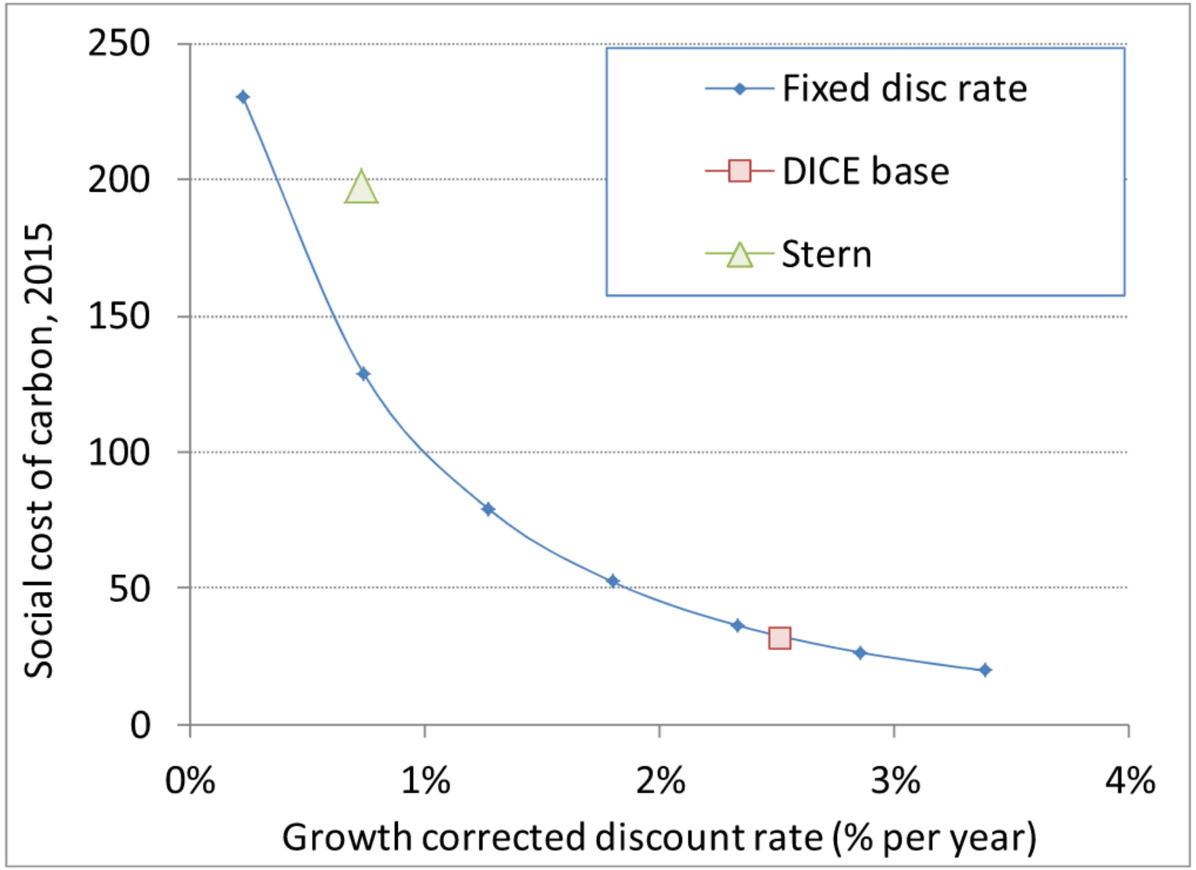
Damage functions

$$\Delta GDP = \beta_1 \Delta GMST + \beta_2 \Delta GMST^2$$

Aside: is this a top-down or bottom-up damage function?

Discounting → Social Cost of Carbon



Social Cost of Carbon Explorer

Resources for the Future has a nice point-and-click IAM (with fixed parameterizations) available to play with on their website

https://www.rff.org/publications/data-tools/scc-explorer/

I recommend exploring it a bit on your own time to better understand the inputs/outputs of each module, and the underlying assumptions.

Next class

- Accounting for Natural Capital:
    - K&O (textbook) Chapter 11
    - Fenichel podcast
    - An Almost Practical Step Toward Sustainability (Solow Monograph)

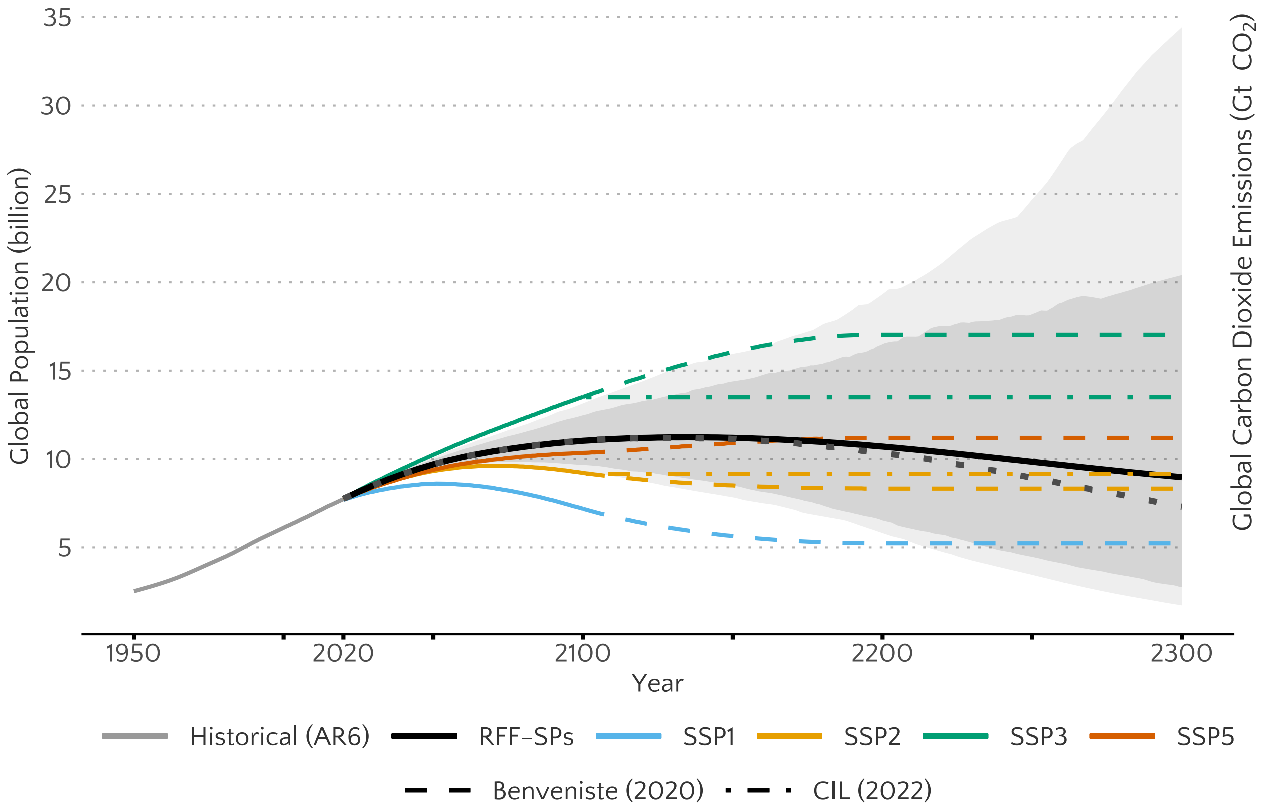
- **Heads up:** Case Study #2 – applying a simple R version of the DICE model!
    - Will post the code files in the next day or so (likely with a slightly delayed due date relative to what's listed on syllabus.)
    - Please, please start early on this and come to us with questions!

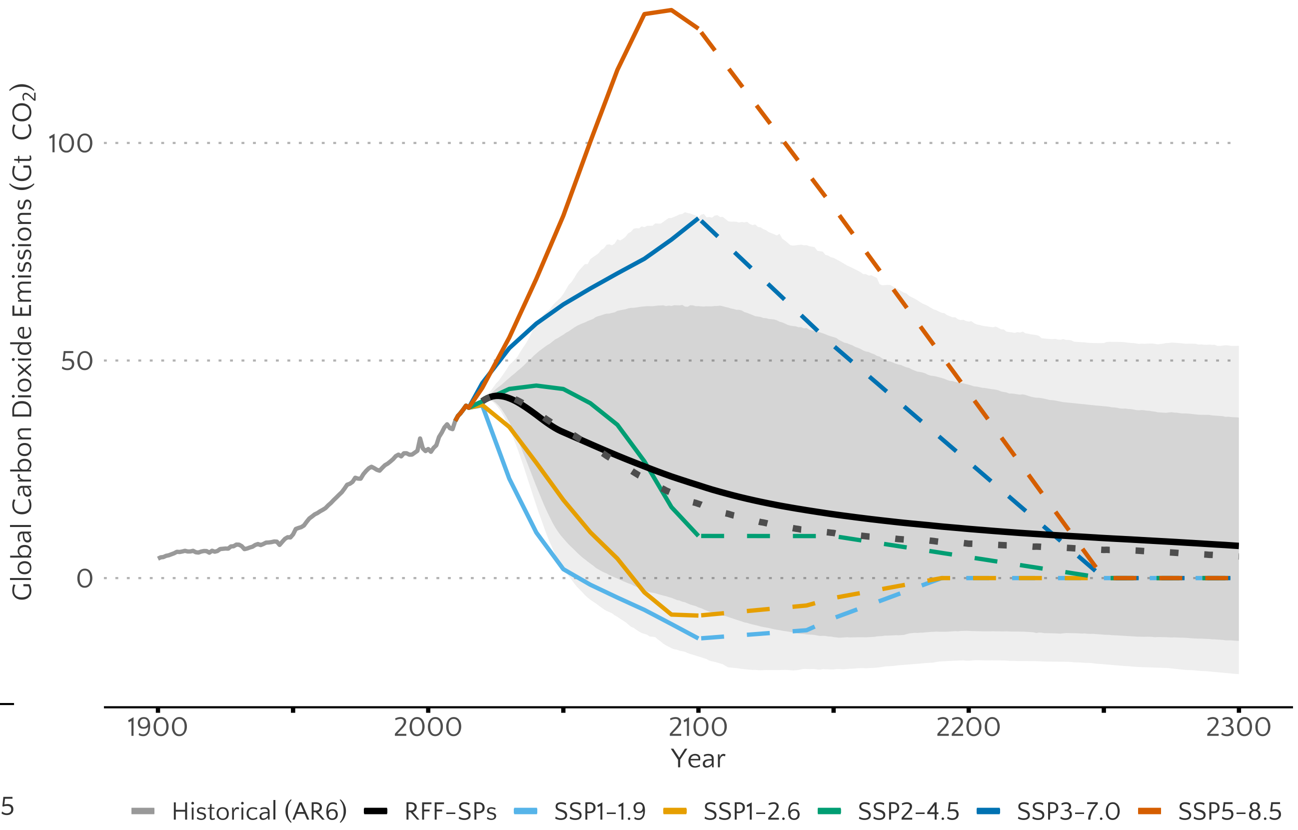
- I will hold open office hours via Zoom this Friday, 4-5pm. See Canvas for details

Appendix: Life Beyond DICE - [Rennert et al. (2022)]

Socioeconomic and emission projections

Statistical probabilistic growth scenarios linked to emissions

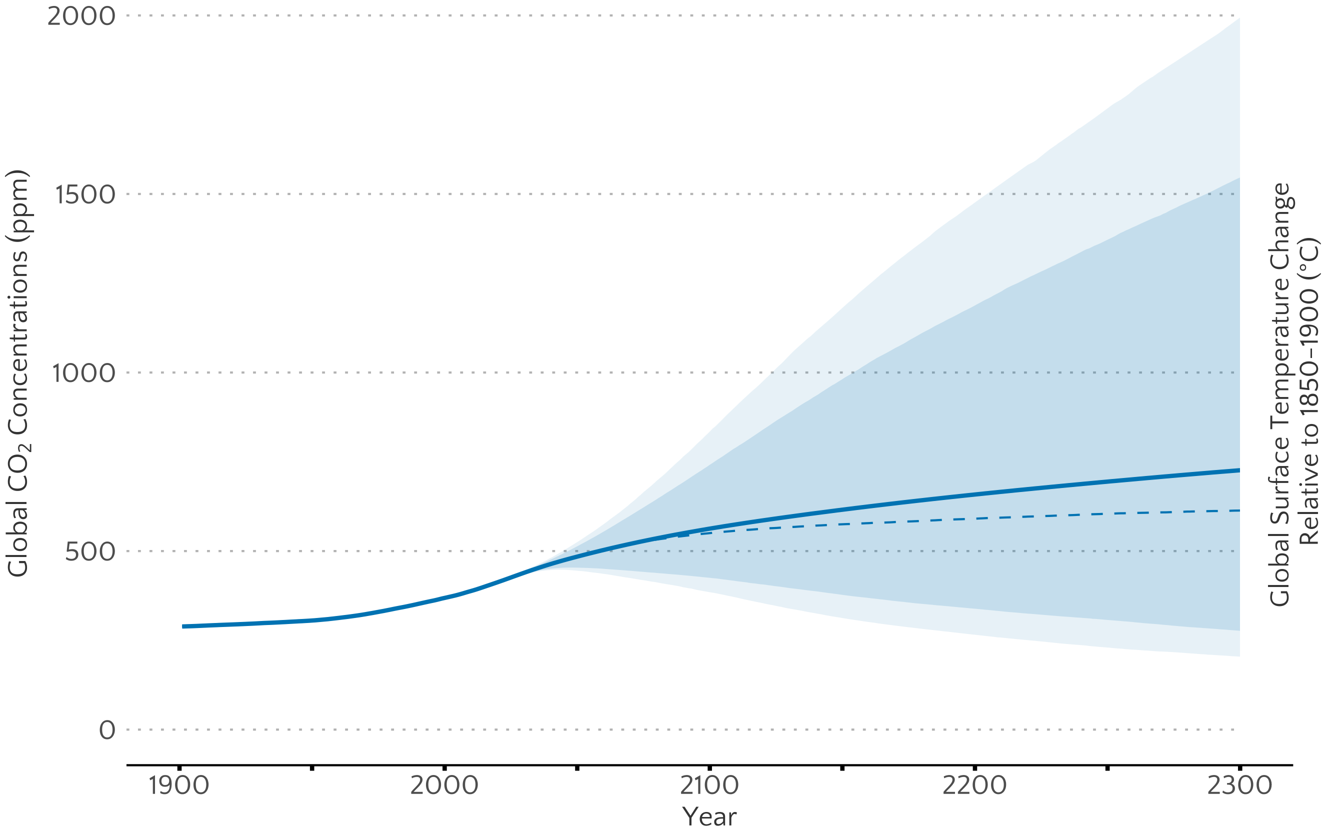


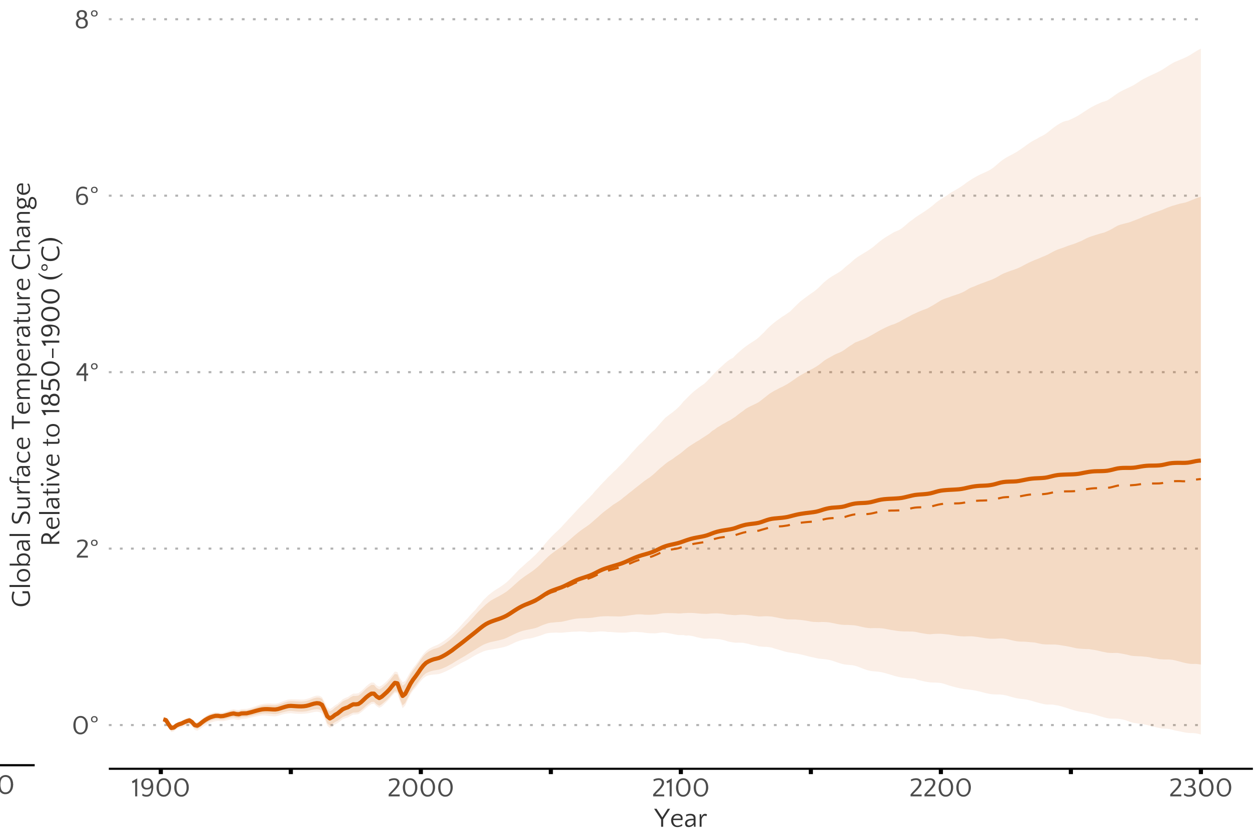


Appendix: Life Beyond DICE - Rennert et al. (2022)

Climate system representation

Reduced complexity climate systems model – FaIR1.6

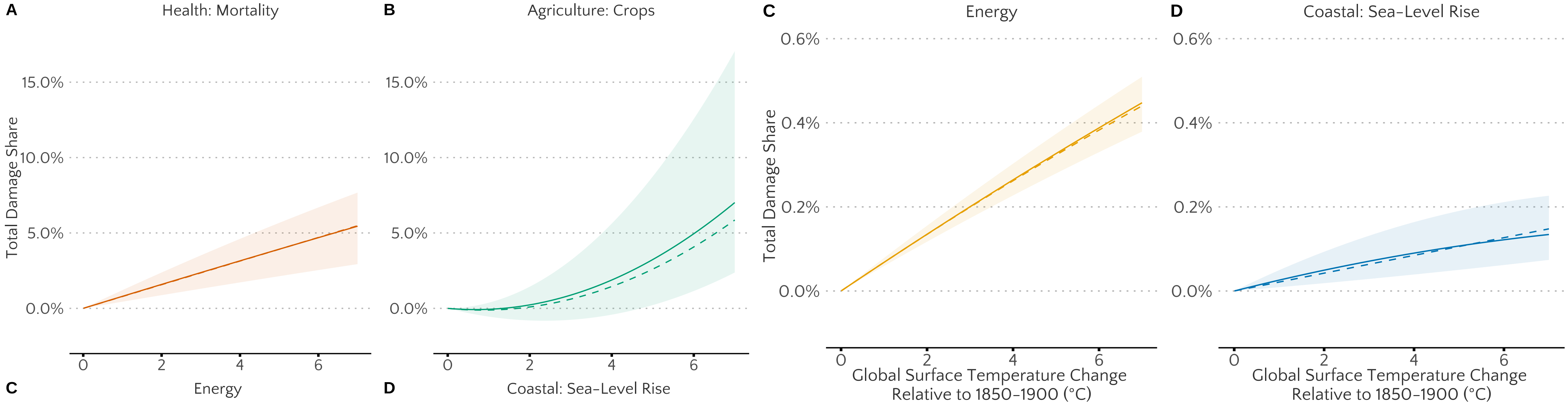




Appendix: Life Beyond DICE - [Rennert et al. (2022)]

Damage functions

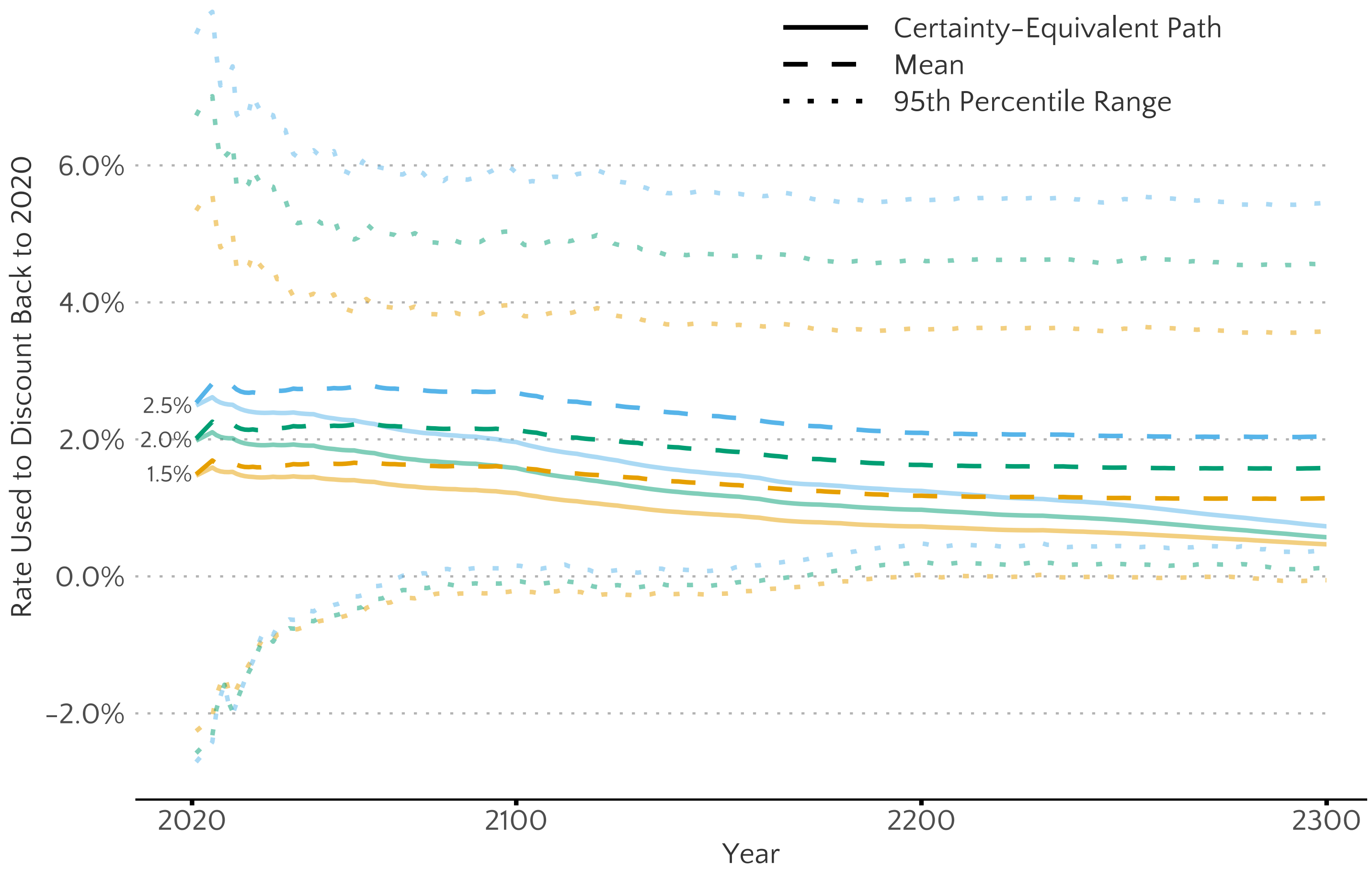
Four-sector damage function at the country-level (184 regions)



Appendix: Life Beyond DICE - Rennert et al. (2022)

Discounting

Dynamic growth-consistent discount rate



Appendix: Life Beyond DICE - Rennert et al. (2022)

Social Cost of Carbon

A social cost of carbon dioxide that is thrice the USG estimate