Economics 134 L7. Climate Change I

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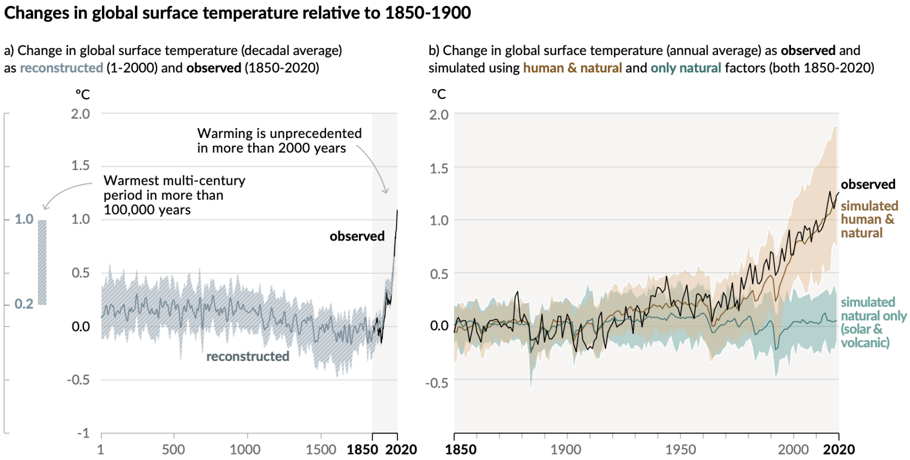
Climate change

Why study climate change?

1. One of the greatest challenges of our time
2. Raises new and interesting economic issues
    1. balancing energy use with decarbonization (today)
    2. discounting and long-run environmental policy (L8)
    3. risk, uncertainty, and irreversibility (L9)
    4. international negotiation and cooperation (L10)

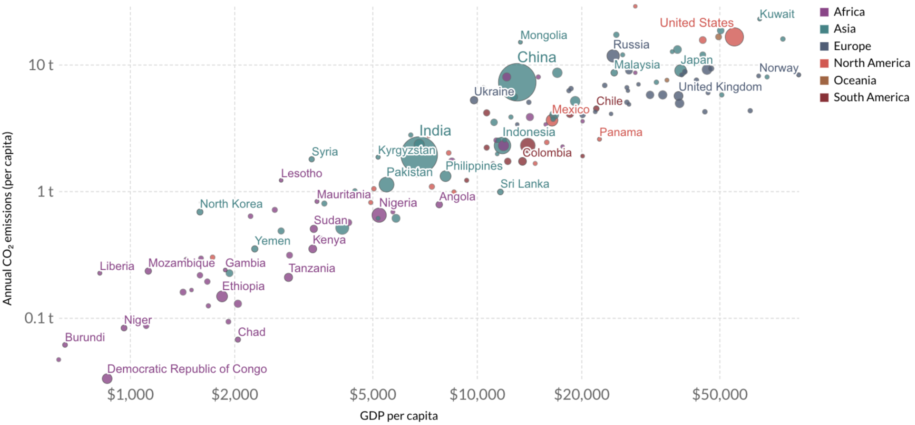
1. Unprecedented rise in global temperature due to CO_2



Source. IPCC August 2021, p. 8

2. Strong correlation between CO_2 and economic output

CO_2 per dollar GDP, across countries



Source: Our World in Data based on the Global Carbon Project, Maddison Project Database 2020 (Bolt and van Zanden (2020))

Plan for today

Today, we'll introduce two sides of the equation:

1. Some economic damages from climate change (benefits to $\downarrow$ temperatures)
2. Some economic value of carbon emissions (costs of mitigation)

and we will study the efficient climate change policies that they imply.

For now, we'll **assume** we know how to (a) value events in the future; (b) deal with uncertain and/or irreversible outcomes; (c) coordinate with every country.

$\hookrightarrow$ each of these assumptions is unrealistic and we **will** relax them all, but it is useful to start with the simplest case.

Estimating climate damages

Estimating the economic damage from climate change involves a few steps:

1. mapping $CO_2 \mapsto$ climate change
   - already demonstrated a robust average relationship ✓
   - predicting **when and where** such changes will occur is much more difficult
   - we will leave this (mostly) to the climate scientists!
2. mapping climate change (e.g., temperature) $\mapsto$ economic damage
   - this is economists' comparative advantage

Some challenges are

- tremendous uncertainty about the details of the climate physics
- the **myriad effects** climate has on a vast range of economic activities

Example: Agricultural yields and temperature

Much of the work underlying the economics of climate change involve looking at **specific industries** and relating changes in **temperature** to outcomes

We'll briefly consider an example, that looks at agricultural yields in the U.S.

- 2.6m workers (1.4% of workforce); $136bn output (0.6% of GDP) in 2020
- world's largest agricultural producer (41%, 38% of world's corn, soybeans)

Paper:

- Schlenker and Roberts (2009), "Nonlinear temperature effects indicate severe damages to U.S. crop yields under climate change," Proceedings of the National Academy of Sciences, **106**(37): 15594–15598.

Empirical strategy

Research strategy: combine detailed spatial data on daily temperature (exposure during growing season) and U.S. crop yields from 1950–2005

In words: compare crops

- grown in the **same** county in **different** years
- controlling for state-specific effects over time

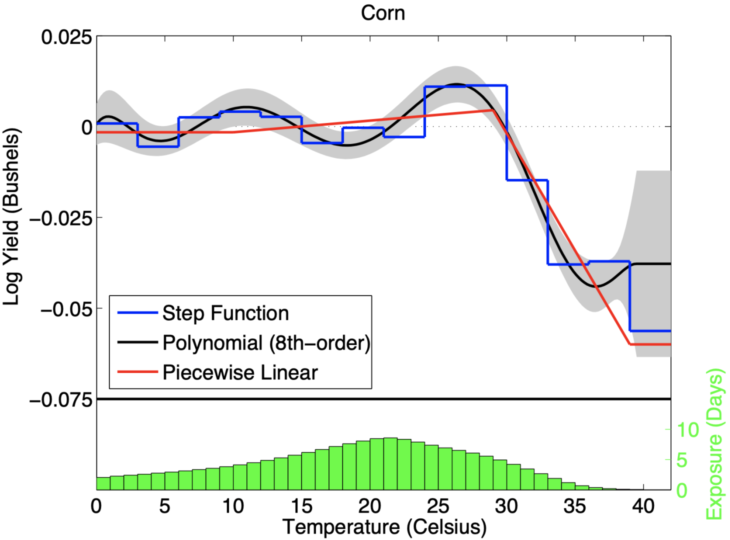
to isolate the effect of hotter days on yields (yield ≡ output/acre).

In math: estimate a nonlinear function g to fit the data:

$$\text{yield}_{it} = g(\text{temperature}_{it}, \text{controls}_{it}) + \varepsilon_{it}$$

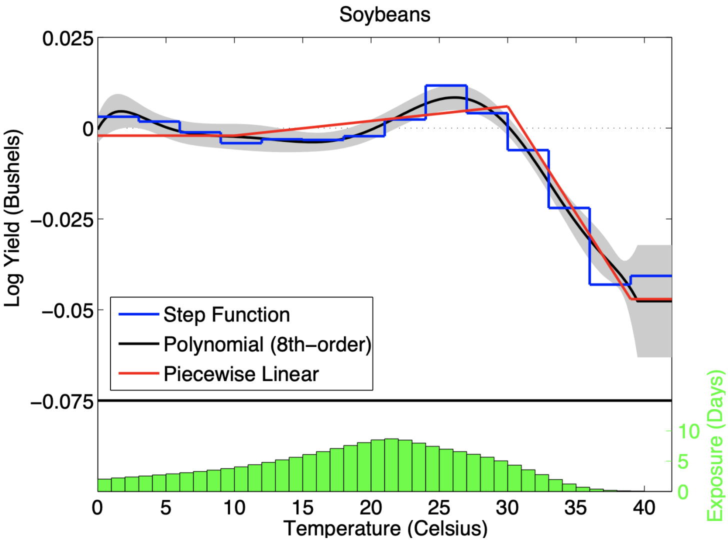
across counties i and years t, given measurement error ε_{it}.

Agricultural yields and temperature: Results



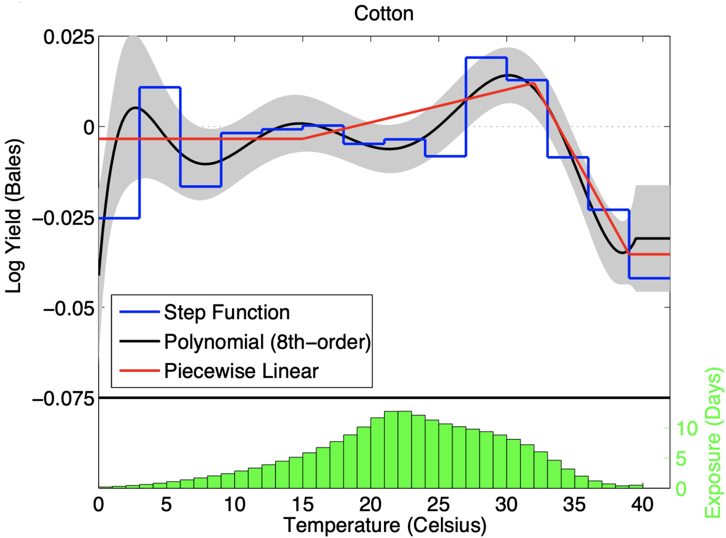
Source. Schlenker and Roberts (2009, Figure 1A, p. 15595).

Agricultural yields and temperature: Results



Source. Schlenker and Roberts (2009, Figure 1B, p. 15595).

Agricultural yields and temperature: Results



Source. Schlenker and Roberts (2009, Figure 1C, p. 15595).

Agricultural yields and temperature: Results

Finding:

- threshold in output effects starting between 29–32°C, depending on the crop
- temperature moderately beneficial until the threshold
- **very harmful** above the threshold

Why should we care?

$\hookrightarrow$ if the distribution of average temperature shifts to the right, then we will see more **very hot** days

We can study this directly, by projecting the estimates into the future using predicted temperatures under future climate change scenarios $\hookrightarrow$

Implications of global warming

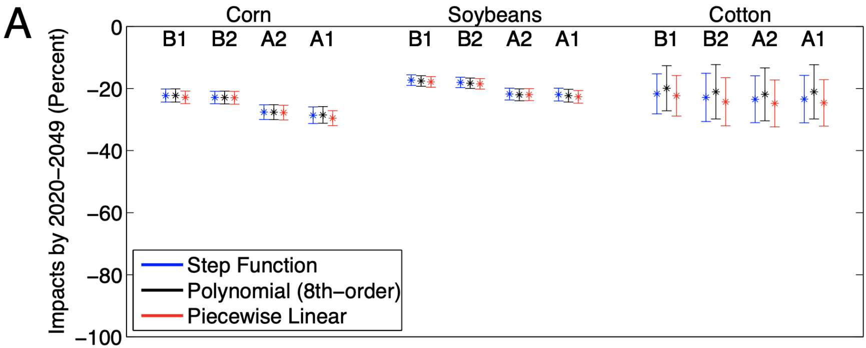
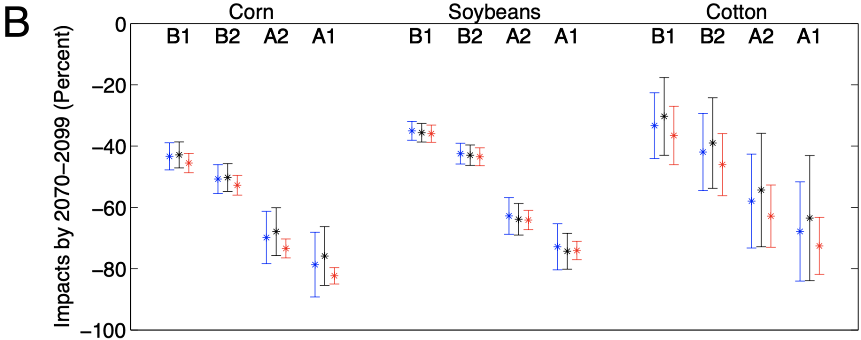


Fig. 2. Predicted climate-change impacts on crop yields under the Hadley III climate model. Graphs display predicted percentage changes in crop yields under four emissions scenarios. Frame A displays predicted impacts in the medium term (2020–2049) and frame B shows the long term (2070–2099). A star indicates the point estimates, and whiskers show the 95% confidence interval after adjusting for spatial correlation. The color corresponds to the regression models in Fig. 1.

Source. Schlenker and Roberts (2009, p. 15595).

Implications of global warming, cont'd



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Source. Schlenker and Roberts (2009, p. 15595).

Many empirical studies

Many other studies proceed along these lines: (a) try to isolate comparisons that control for omitted variables, and then (b) learn about the effects of temperature on outcomes of economic interest.

For example, economists have found

- hotter days increase mortality (Barreca et al. 2015)
- hotter days reduce worker productivity (Heal and Park 2016)
- hotter days increase workplace injuries (Park, Pankratz, and Behrer 2021)
- higher annual temperatures lower economic growth in developing countries (Dell, Jones, Olken 2012)
- hurricanes and tropical storms reduce long-run economic output (Hsiang 2010)

See Dell, Jones, Olken 2014 (course website) for one synopsis.

Caveat

Important distinction to keep in mind: **climate** $\neq$ weather

- **climate**: distribution of weather outcomes
- **weather**: realization of climate (e.g., today's temperature or rainfall)

Commentators (and economists!) frequently confuse the two.

But the distinction is crucial for economic analysis:

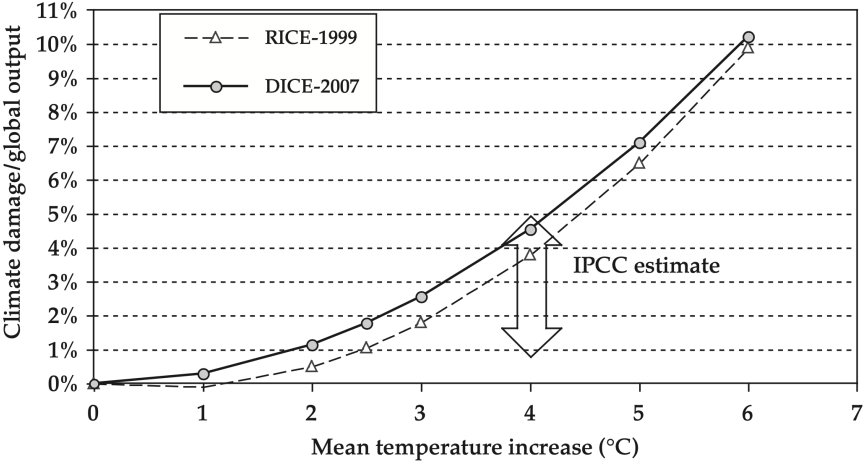
- **climate change** is somewhat permanent and should affect longer-run economic decisions (where to live, where to work, what technology to invent)
- changes in the **weather** may be transient and entail very different economic responses

Discussion

General idea of constructing a damage function:

- obtain a **lot** of these small estimates
- add them up to obtain total damage for each sector and each county for a given increase in temperature
- use to trace out the **aggregate** climate damages curve as a function of the temperature increase

Aggregate climate damage function



Three ways to prevent climate change

Broadly, three strategies for slowing climate change:

1. **Reduce emissions** from economic production
2. Directly remove carbon from emissions or the atmosphere (**carbon removal**)
3. Engineer the climate directly (**geoengineering**) or engage in other adaptation strategies.

With the possible exception of (3), each of these strategies will play a role in our response to climate change.

We'll discuss them in reverse order.

3. Geoengineering

Conceptually straightforward (cloud seeding since the 1970s; well-established link between volcanic eruptions and temperature reductions); **very** inexpensive.

Details are much murkier.

Possibly very bad side effects.

Bottom line:

- geoengineering may or may not be allowed
  - even proponents agree that it is dangerous to rely exclusively on untested technology to radically alter the environment
  - some concerns that the prospect of geoengineering itself may delay the transition to clean technology (e.g., Acemoglu and Rafey 2023)
- adaptation should and will be undertaken, but it's not free

2. Carbon removal

Highly attractive in principle: reverse combustion!

Difficult in practice: **very costly** per ton of carbon, both in terms of money and also energy

- lots of engineers trying to solve this problem, but limited progress

Trees offer a natural solution, though require continuous monitoring + management.

$\hookrightarrow$ we'll discuss this more later in the course!

1. Reduce emissions

Lowering emissions (abatement):

- policymakers' **main focus** since the first UN assessment (IPCC, 1990)
- "the only realistic option to deal with climate change" (Nordhaus 2018, p. 447)

Broadly, two complementary strategies:

- **substitute** away from fossil-fuel intensive production towards different activities that do not use fossil fuels
  - e.g., switch from coal to natural gas, nuclear, or renewables for electricity generation (or stop consuming energy entirely)
- **better technology** to improve the efficiency of carbon-based production
  - e.g., more efficient internal combustion engines; electric cars

1. Reduce emissions, cont'd

From an economic perspective, **both should entail costs**.

$\hookrightarrow$ If individuals (firms) are maximizing utility (profits), economic theory indicates that distorting their decisions will entail some costs for these individuals (firms).

Of course, this does not suggest that such costs will exceed the benefits.

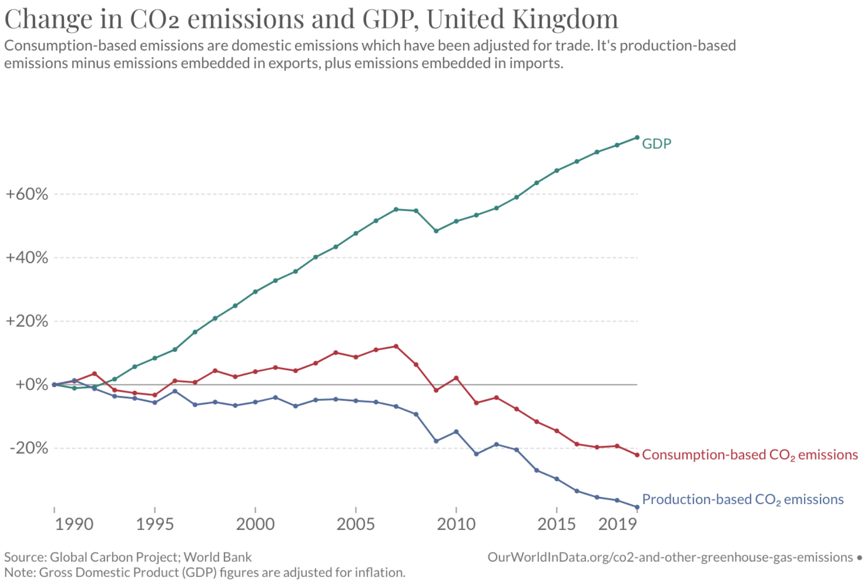
1. Reduce emissions, cont'd

Substitution and more efficient technology each can be important.

In the U.K.,

- largely phased out coal
- substantially increased share of renewables for electricity
- outsourced emissions to other countries with trade

UK emissions, 1990–2020



1. Reduce emissions, cont'd

Substitution and more efficient technology each can be important.

In the U.K.,

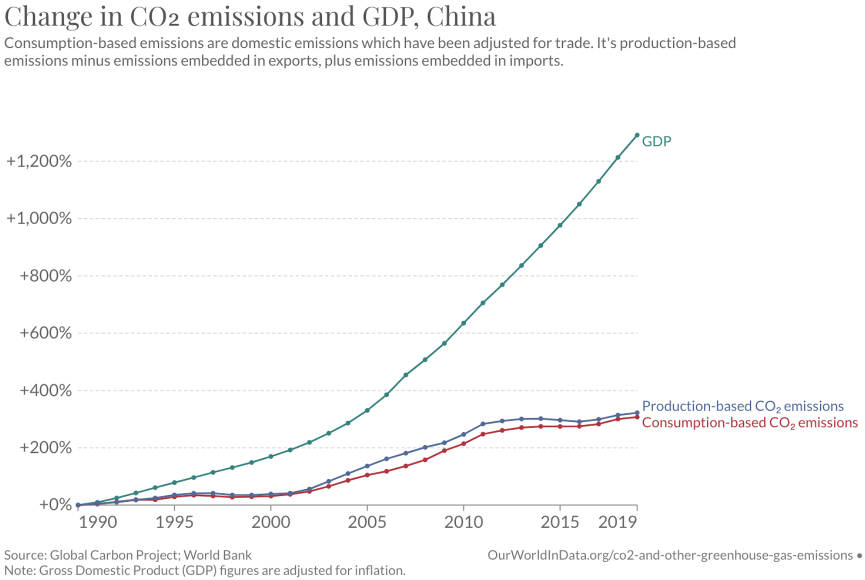
- largely phased out coal
- substantially increased share of renewables for electricity
- outsourced emissions to other countries with trade

In China,

- still a very coal-intensive, rapidly growing industrial economy
- significant decline in "emissions intensity" largely due to replacing older coal plants with newer, much more efficient coal power plants

Of course, always do both: China has invested substantially in renewables; the UK has also invested in more efficient technology.

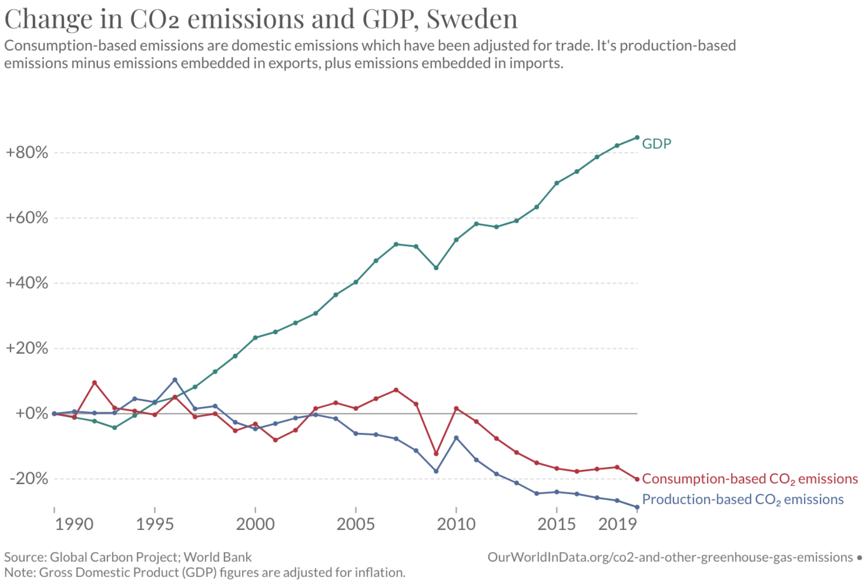
China's emissions, 1990–2020



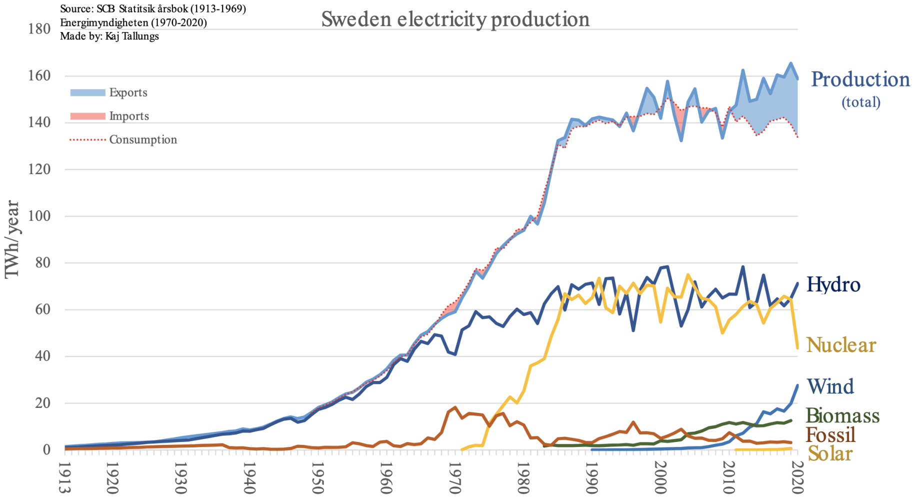
A last example: Sweden

Often hailed as a success story. $\hookrightarrow$

A last example: Sweden



Sweden endowed with renewable energy since 1970s



Sweden's carbon emissions and carbon tax

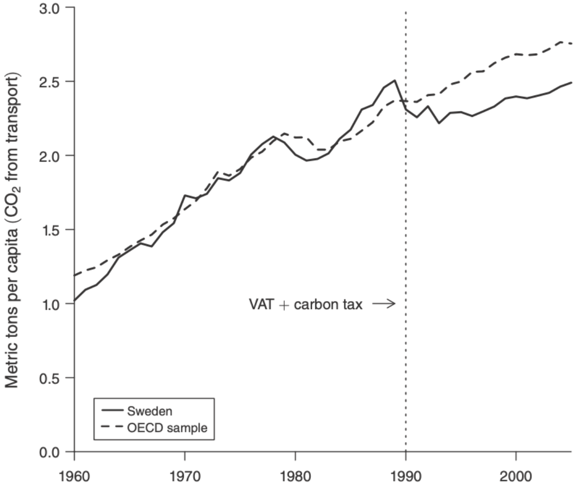


FIGURE 3. PATH PLOT OF PER CAPITA CO_2 EMISSIONS FROM TRANSPORT DURING 1960–2005: SWEDEN VERSUS THE OECD AVERAGE OF MY 14 DONOR COUNTRIES

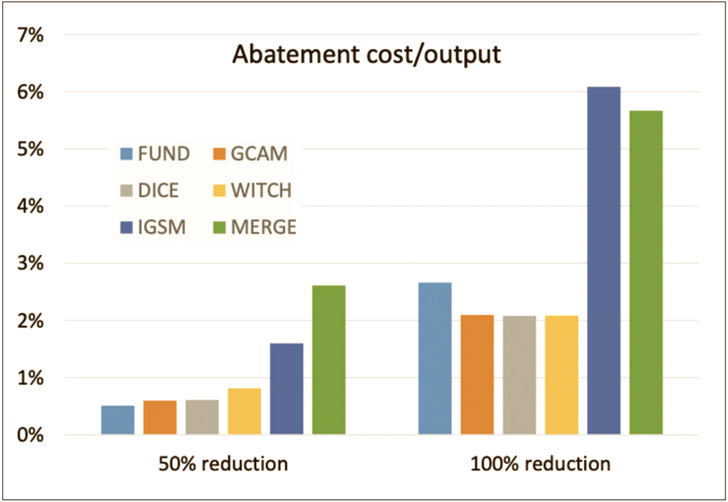
Source. Andersson (2019, AEJ: Economic Policy **11**(4): 1–30).

Discussion

Similar to economic damages from climate change, the idea is to

- add up the costs of switching to lower-carbon activities
- account for innovation and technical change over time
- for each level of global emissions, calculate the total abatement costs (relative to not doing anything or "business-as-usual")
- use these estimates to construct costs for different levels of climate policy

Abatement costs across various models



Source. Nordhaus (2018, p. 447).

Not on an exam

If you're curious, the models in the previous figure are:

- **FUND** (Climate Framework for Uncertainty, Negotiation and Distribution) at the University of Sussex
- **DICE** (Dynamic Integrated Climate Change) at Yale
- **IGSM** (Integrated Global System Modeling) at MIT
- **GCAM** (Global Change Analysis Model) at the University of Maryland
- **WITCH** (World Induced Technical Change Hybrid) at the European Institute on Economics and the Environment, Milan
- **MERGE** (Model for Estimating the Regional and Global Effects of Greenhouse Gas Reductions) at the Electric Power Research Institute, Washington DC
- **PISCES** (Psychological Intelligence Schemes for Expediting Surrender) at The White Visitation

Integrated assessment modeling

Recall our solution to externalities:

$$\pi'(q^{\mathsf{FB}}) - D'(q^{\mathsf{FB}}) = 0. \tag{$\star$}$$

In this case,

- marginal profits depended on output (higher q, lower marginal profits)
- marginal damage depended on output (higher q, higher marginal damages)

Now, suppose q is carbon emissions:

- marginal abatement cost $(-\pi')$ depends on speed of emission reductions
- marginal benefit of reducing emissions (D') depends on total carbon stock

Nordhaus' Nobel Prize contribution: an "integrated assessment model" that tries to find q^{FB} by solving a dynamic version of $(\star)$ that incorporates climate physics.

Key contributions

Nordhaus' research has led directly to two important outcomes:

1. the **social cost of carbon** (i.e., D'), which, from our previous lectures, we know relates to the optimal carbon tax
2. a systematic way to evaluate different climate policies (emissions trajectories) with **cost-benefit analysis**

Social cost of carbon

The social cost of carbon is calculated as $D'(q)$, the marginal damage of an additional ton of carbon dioxide:

	Social Cost of Carbon [2018 $ per ton of CO2]			
Year	2015	2020	2050	2100
Base	37	45	108	304
Optimal	36	43	105	295
Optimal (alt dam)	91	108	249	584

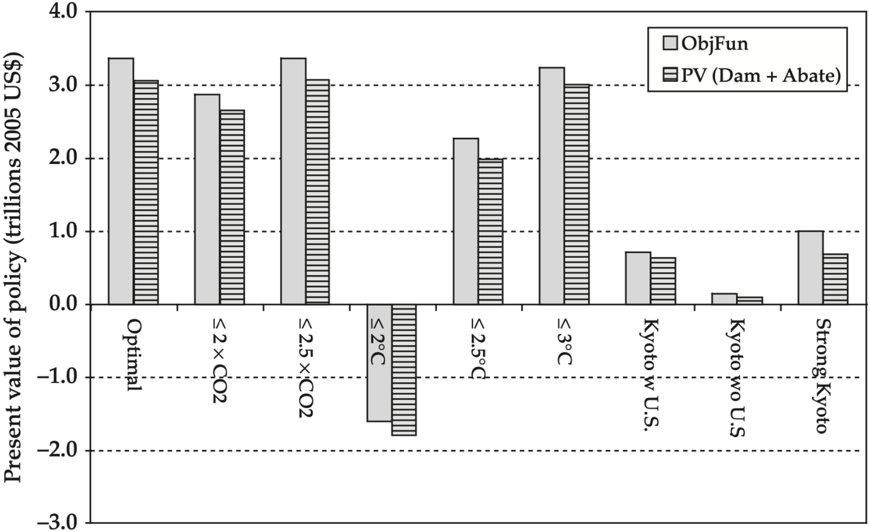
Source. Nordhaus (2018, Table 1, p. 454).

Discussion

Key insights:

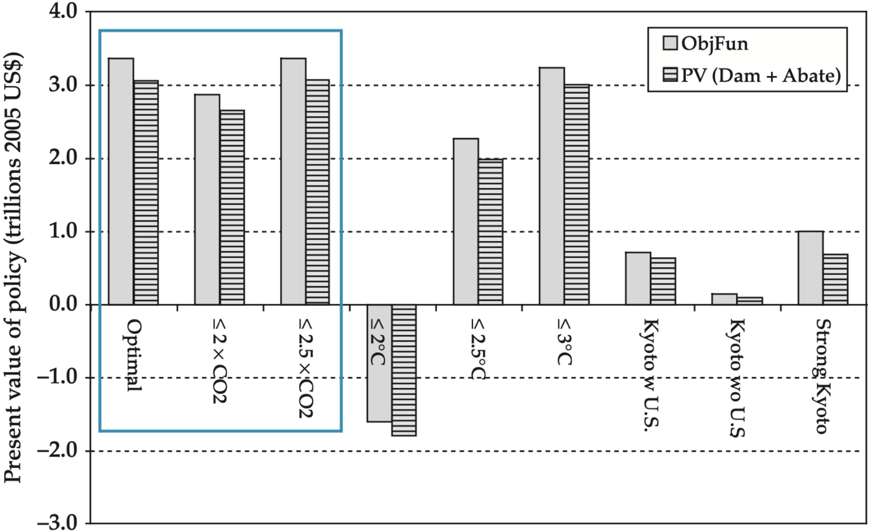
- **huge** net benefits for climate policy relative to inaction
- start emissions reductions **as soon as possible**
- ramp up **over time**, to give firms time to adapt
- more stringent targets entail **much higher costs**. . .

Net benefits of different policies



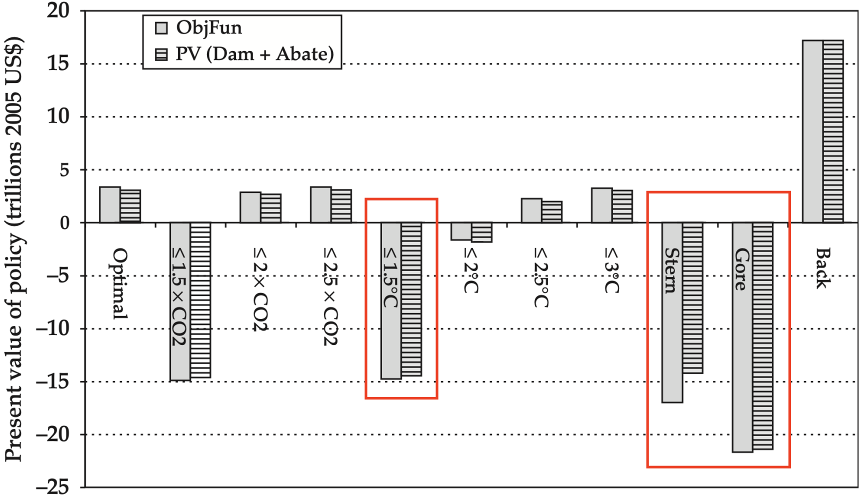
Source. Nordhaus (2008, Figure 5-2, p. 86).

Net benefits: Optimal targets



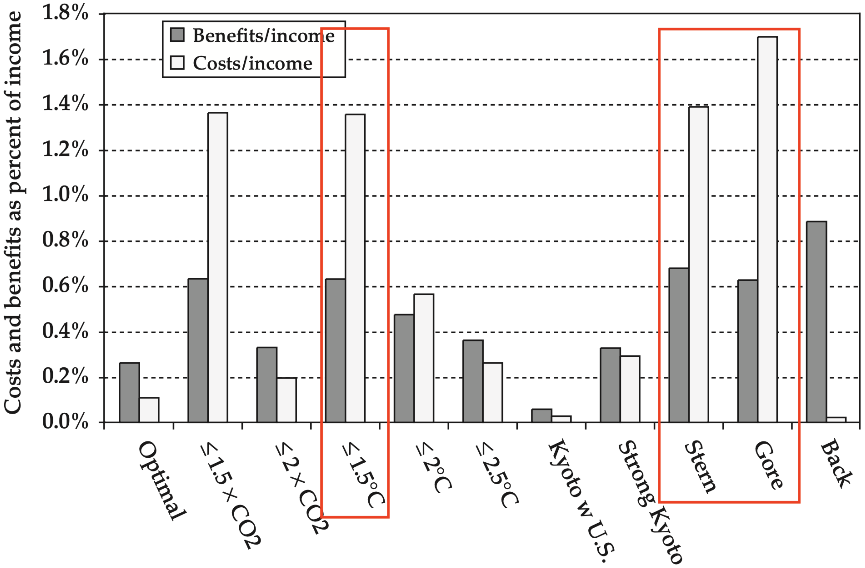
Source. Nordhaus (2008, Figure 5-2, p. 86).

Net benefits: Stricter climate targets

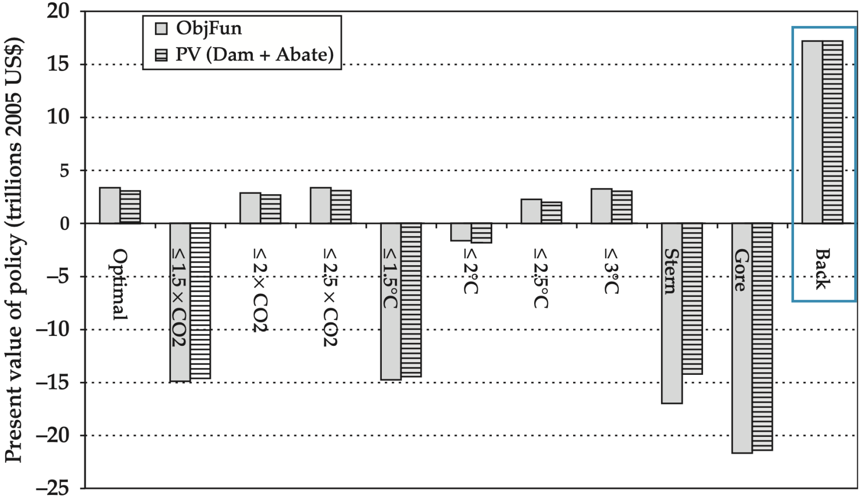


Source. Nordhaus (2008, Figure 5-1, p. 85).

Benefits v. costs: Stricter climate targets

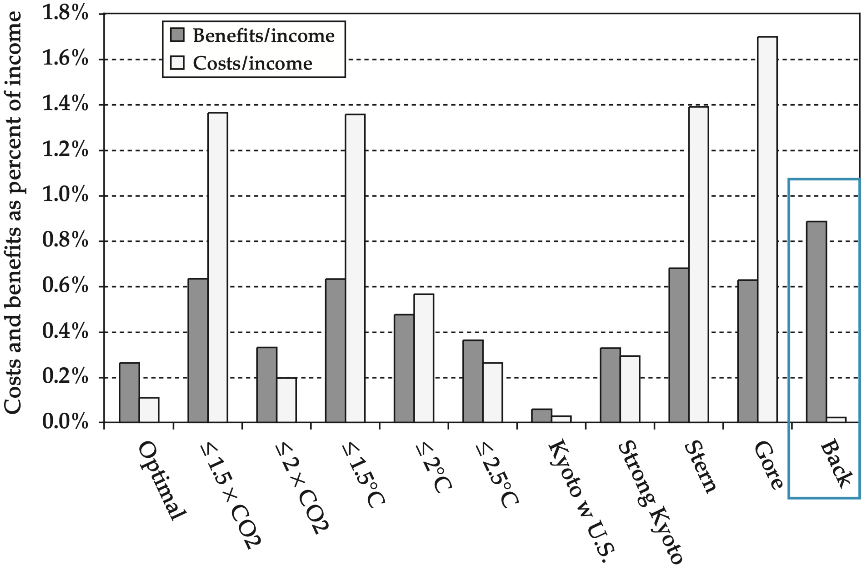


Technological breakthrough



Source. Nordhaus (2008, Figure 5-3, p. 90).

Technological breakthrough



Technological breakthrough

"We estimate that such a low-cost zero-carbon technology would have a net value of around **$17 trillion in present value** *because it would allow the globe to avoid most of the damages from climate change" (Nordhaus 2008, p. 19)*

Next Monday

Consider reading:

- Nordhaus (2018), "Climate change: The ultimate challenge for economists," Nobel Prize Lecture, December 8, 2018 (on the website)

No other homework.