Energy and climate economics: how to get the carbon price right?

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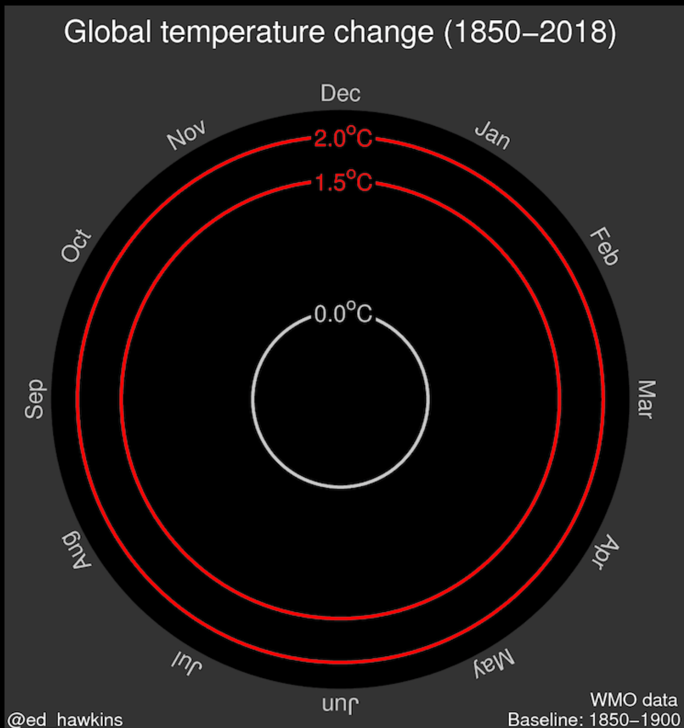
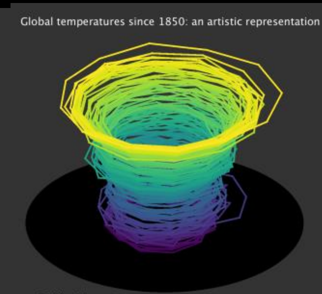
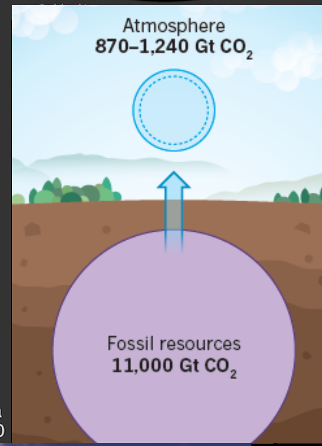


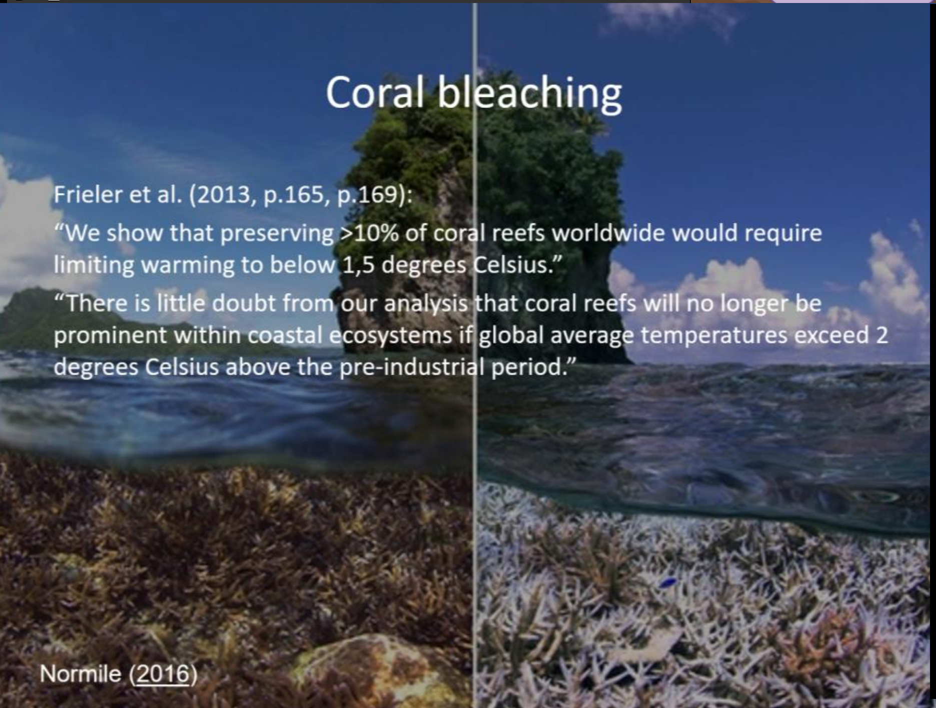




Amphibian decline

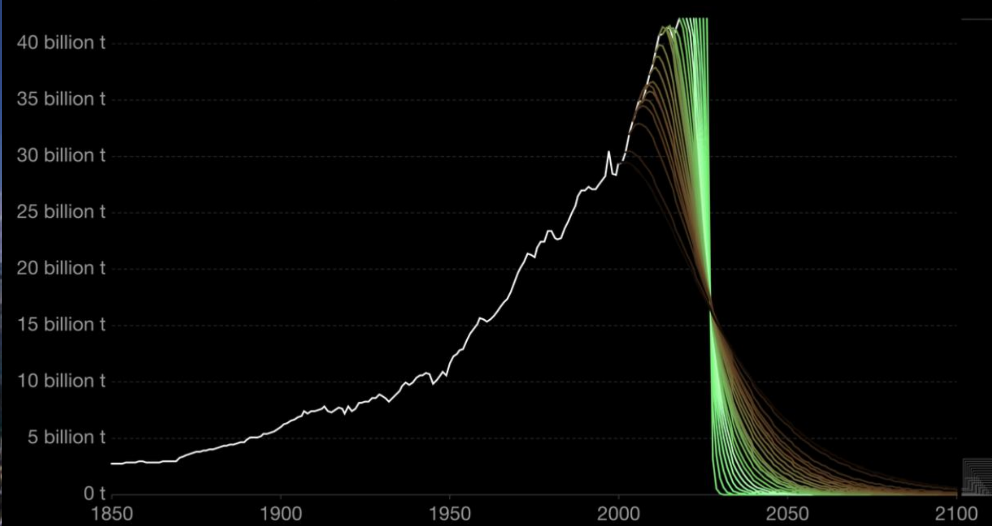
Pounds et al. (2006): "Seventeen years ago, in the mountains of Costa Rica, the Monteverde harlequin frog (*Atelopus sp.*) vanished along with the golden toad (*Bufo periglenes*). An estimated 67% of the 110 or so species of *Atelopus*, which are endemic to the American tropics, have met the same fate, and a pathogenic chytrid fungus (*Batrachochytrium dendrobatidis*) is implicated."

Atelopus sp., National geographic photo Ark



CO_2 reductions needed to keep global temperature rise below 1.5°C

Annual emissions of carbon dioxide under various mitigation scenarios to keep global average temperature rise below 1.5°C. Scenarios are based on the CO_2 reductions necessary if mitigation had started – with global emissions peaking and quickly reducing – in the given year.



Source: Robbie Andrews (2019); based on Global Carbon Project & IPPC SR15
Note: Carbon budgets are based on a >66% chance of staying below 1.5°C from the IPCC's SR15 Report.

Cost-benefit vs. cost-efficiency analysis

Cost-benefit approach: Set carbon price equal to SCC, where SCC is an estimate of marginal damage in the social optimum

Advantages (Aldy et al. 2021):

- Scientific rather than political
- International cooperation
- Legal integration US policy

Keep climate policy focused on the social cost of carbon

A proposed shift away from the SCC is ill advised

By **Joseph E. Aldy[1,2,3], Matthew J. Kotchen[2,4], Robert N. Stavins[1,2,3], James H. Stock[1,2,3,5]**

Cost-efficiency approach: Target-consistent prices (or corridors) based on switching prices and embedded in complementary regulation.

Advantages?

- Closer in line with precautionary principle
- Shorter analysis horizon
- Systems approach may allow integration of co-benefits

Perman et al. (2003, p.141):

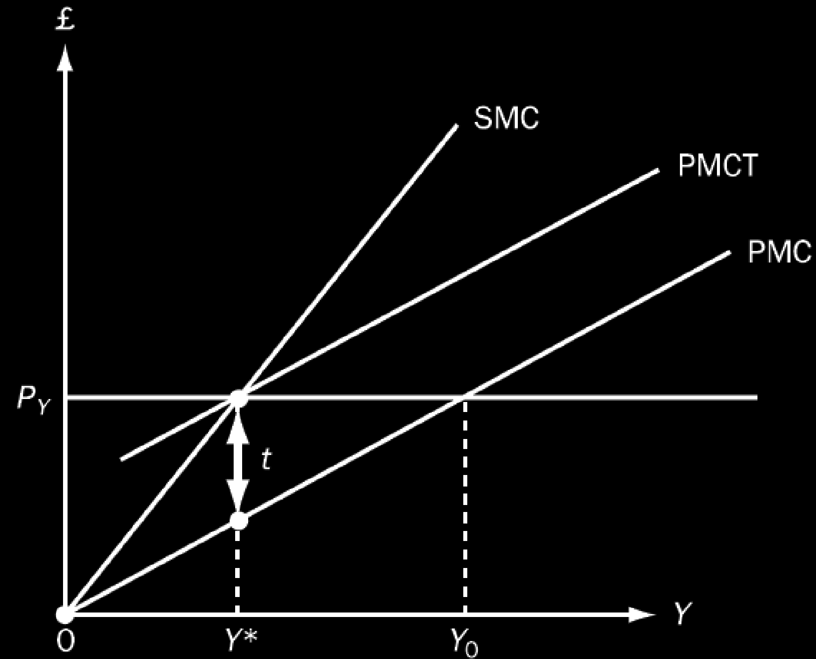


Figure 5.14 Taxation for externality correction

Coady et al. (2019, p. 8):

"'social cost of carbon' (SCC)—the discounted value of worldwide damages from the future global climate change associated with an additional ton of current emissions—"

Tol (2018, p.10):

"The social cost of carbon is defined as the monetary value of the first partial derivative of global, net present welfare to current carbon dioxide emissions. It is sometimes calculated as a true marginal along a welfare-optimizing emissions trajectory, and so equals the Pigou (1920) tax on carbon dioxide."

Integrated Assessment Models (IAM)

Prototypical model (Nordhaus 2019, p. 1995):

$$\max_{c(t)} W = \max_{c(t)} \left[\int_0^{\infty} U[c(t)] e^{-\rho t} dt \right]$$

subject to

$$c(t) = M(y(t); z(t); \alpha; \varepsilon(t)).$$

where "c(t) is consumption; y(t) are other endogenous variables (such as global temperature); z(t) are exogenous variables (such as population); α are parameters (such as climate sensitivity); ρ is the pure rate of time preference; and ε(t) are random variables in the stochastic versions." Nordhaus (2019), p. 1995

Nordhaus (2019, p. 2000): "Here is the basic intuition: The DICE model estimates the path of the economy that optimizes consumption, emissions, and climate change. … These calculations take into account the production functions of the economy, the constraints of the carbon cycle, and the rest. One of the auxiliary byproducts of the calculations is an estimate of the impact on optimized consumption of an extra ton of emissions. … "

"… *The DICE model produces this shadow price as part of the solution—the shadow price is a mathematical variable associated with carbon emissions in an optimized framework. Later, this was interpreted as the carbon price or carbon tax associated with internalizing the carbon externality*."

Nordhaus (2017, p.1521): $$\mathrm{SCC}(t) \equiv \frac{\partial W}{\partial E(t)} \Big/ \frac{\partial W}{\partial C(t)} \equiv \partial C(t) / \partial E(t).$$

SCC estimates depend strongly discount rates

Nordhaus (2019, p. 2006):

	Social cost of carbon 2018$ per ton of CO_2			
Discount rate (%)	2015	2020	2050	2100
0.1	970	966	917	665
1.0	497	515	614	657
2.0	219	236	349	544
3.0	93	104	179	361
4.0	44	49	93	207
5.0	23	27	55	126
DICE-opt	36	43	105	295

Stern et al. (2022): 'DICE-optimal' leads 3.5 – 4 Celsius warming

Aldy et al. (2021) on SCC in USA: "The administration recently issued its interim SCC, with a primary value of $51/ton and ranging from $14 to $152/ton (in 2020 US dollars)."

Certainty equivalent declining discount rate

See Arrow et al. 2013 for an introduction

Discount factors and certainty equivalent discount rate

t	Value of $1000 after t years				Certainty equivalent discount rate
	1%	4%	7%	1% or 7%	
1	$990	$961	$932	$961	3.9%
10	$905	$670	$497	$701	3.1%
100	$368	$18	$1	$184	1.7%

Source: Tol (2014, p. 127)

The certainty equivalent is equal to the lowest discount rate for the distant future (see Weitzman, 1998 for proof)

Climate sensitivity and tail risks

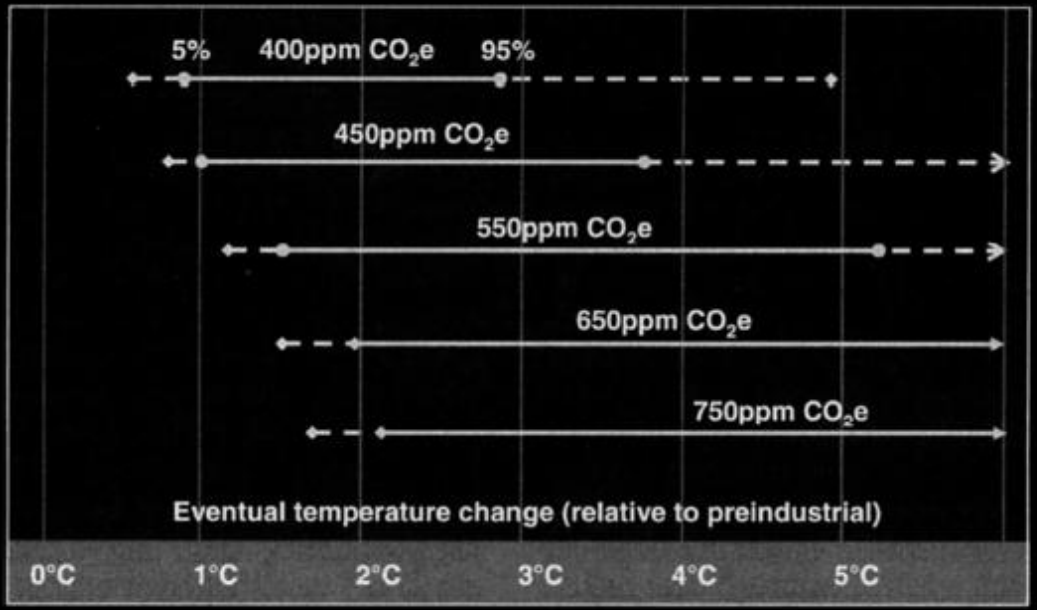


FIGURE 1. STABILIZATION AND EVENTUAL CHANGE IN TEMPERATURE

Source: Stern Review, Table 1.1 (Stern 2007, 16); Meinshausen 2006; Wigley and Raper 2001; Murphy et al. 2004.

TABLE 1—LIKELIHOOD (IN PERCENTAGE) OF EXCEEDING A TEMPERATURE INCREASE AT EQUILIBRIUM

Stabilization level (in ppm CO_2e)	2°C	3°C	4°C	5°C	6°C	7°C
450	78	18	3	1	0	0
500	96	44	11	3	1	0
550	99	69	24	7	2	1
650	100	94	58	24	9	4
750	100	99	82	47	22	9

Pindyck (2017, p. 349): “Putting aside the discount rate problem, because of the current limitations of climate change science, these models simply make assumptions about *climate sensitivity*, that is, the temperature increase that would result from a doubling of the atmospheric CO_2 concentration. …”

“ … And the models, which generally focus on the most likely outcome, tell us nothing about *tail risk*, that is, the likelihood and possible impact of a catastrophic climate outcome, and the key driver of the SCC.”

Cai et al. (2016) inclusion of tipping points gives 8 larger SCC

Source Figure & Table: Stern (2008)

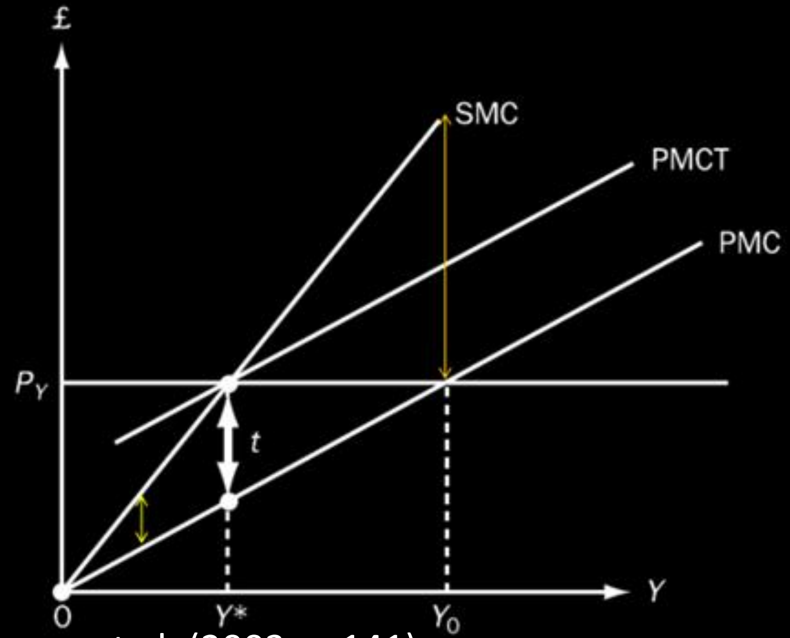
Ad-hoc damage functions

Pindyck (2013, p. 868): “Sometimes these numbers are justified by referring to the IPCC or related summary studies. For example, Nordhaus (2008) points out that the 2007 IPCC report states that "global mean losses could be 1-5 percent GDP for 4°C of warming". But where did the IPCC get those numbers? From its own survey of several IAMs. Yes, it’s a bit circular.”

Questionable commensurability

Arrow et al. (1996, p. 221): “We offer the following eight principles on the appropriate use of benefit-cost analysis: 1) Benefit-cost analysis is useful for comparing the favorable and unfavorable effects of policies. …”

Problematic optimal (growth) path assumption (Hickel and Kallis, 2020)



Perman et al. (2003, p.141)

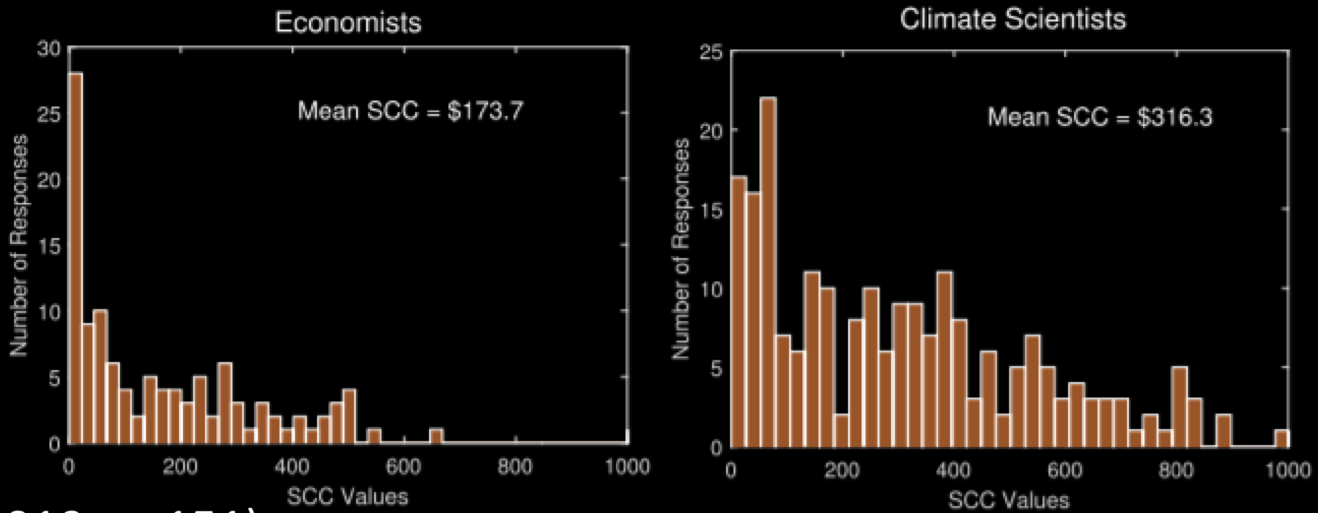
Figure 5.14 Taxation for externality correction

Pindyck (2017, p. 349): "The difficulty with the use of IAMs for policy analysis goes beyond their arbitrary parameter assumptions and *ad hoc* damage functions. The greater problem, discussed in detail in Pindyck (2017), is that they create a perception of knowledge and precision that is illusory, and can mislead policymakers into thinking that the forecasts generated by the models have some kind of scientific legitimacy."

Pindyck (2017, 2019)

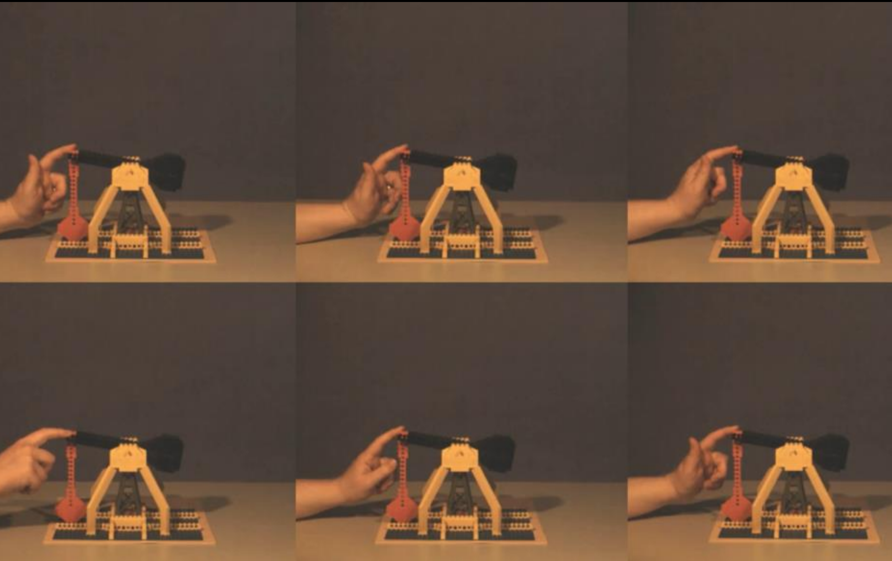
Pindyck proposes to use average social costs of carbon instead of marginal SCC, because the average:

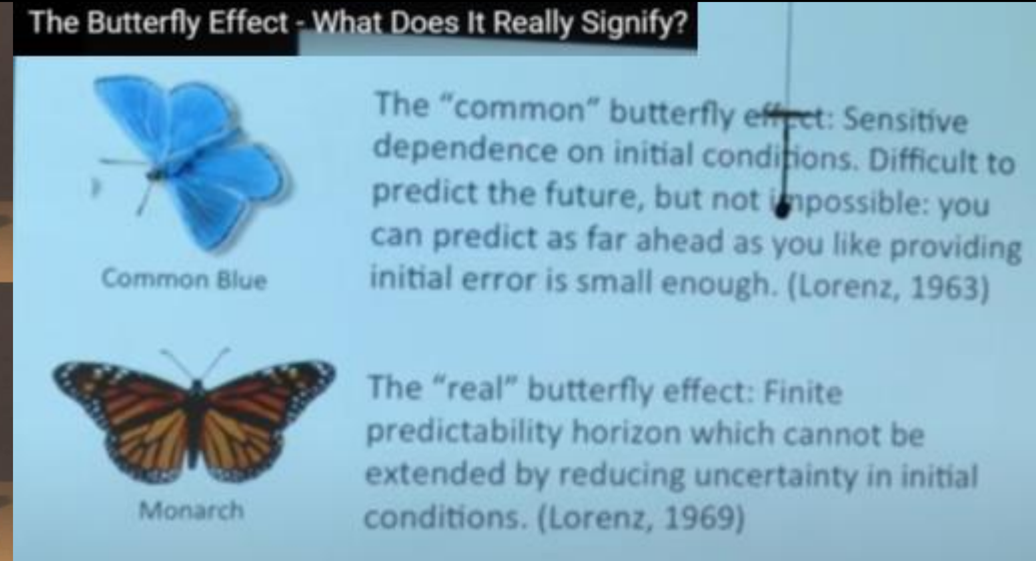
- Is less sensitive to being on the optimal path
- Does not change over the estimated period
- Has lower sensitivity to discount rate
- Estimation by using expert opinion is transparent about the subjective nature

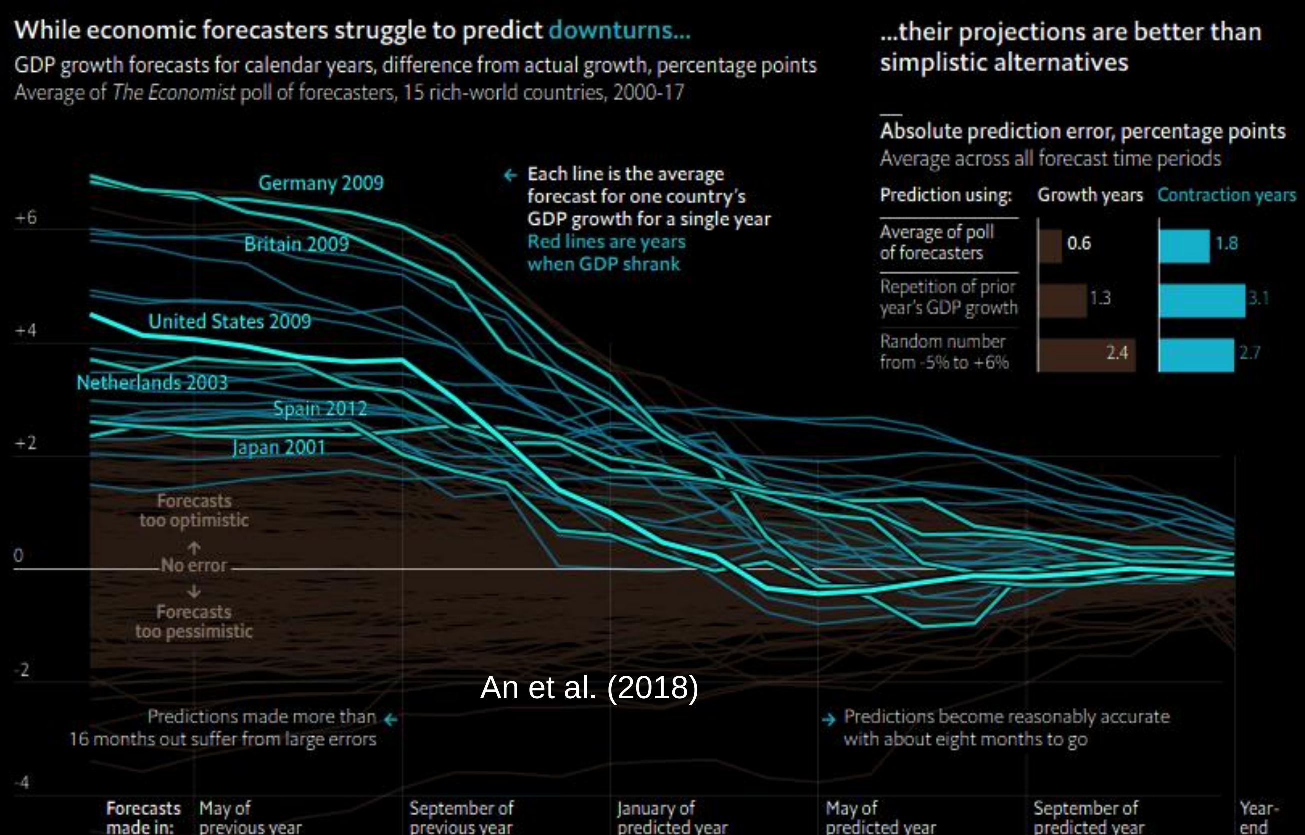


Pindyck (2019, p. 151)

Fig. 1. SCCs from individual responses, by group, using distribution with highest R^2.







An et al. (2018)

History vs. expectations

Krugman 1991

Cost-benefit vs. cost-efficiency analysis

Cost-benefit approach: SCC is an estimate of marginal damage in the social optimum

Advantages (Aldy et al. 2021):

- Scientific rather than political
- International cooperation
- Legal integration

Challenges to SCC estimation

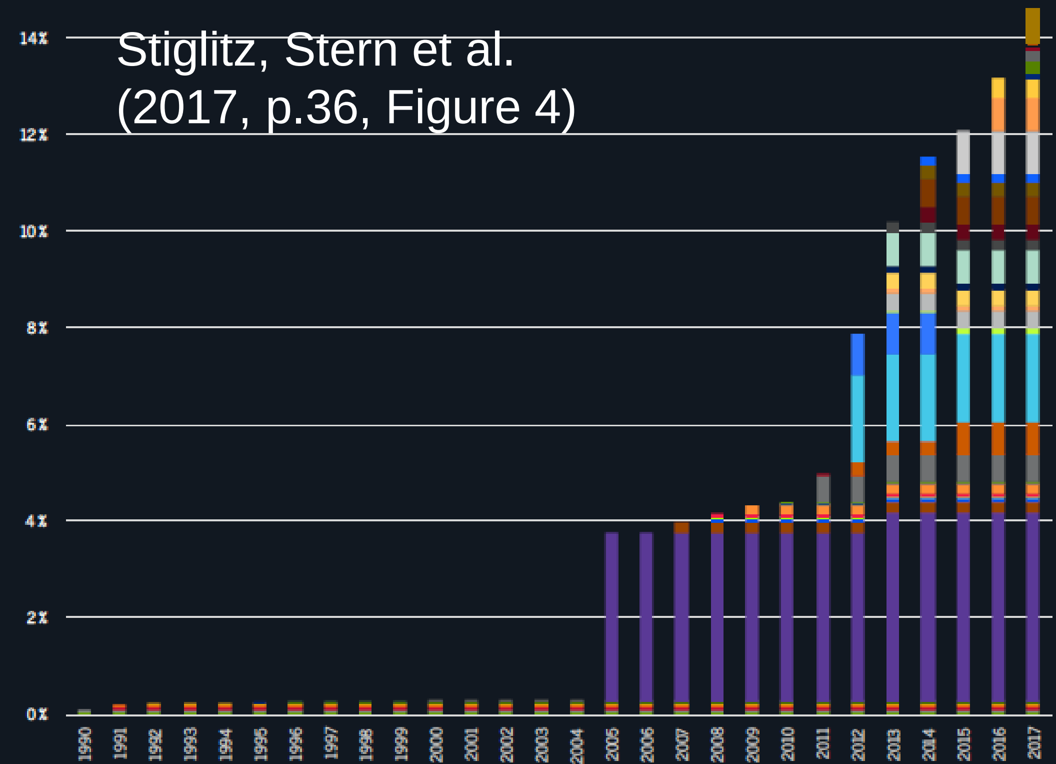
- Strong dependence on discount rates
- Poor attention to climate sensitivity, tail risks, tipping points
- Strong assumptions damage functions
- Growth as optimal by assumption
- Impossibility to model catastrophes
- Limits to prediction horizon

Cost-efficiency approach: Target-consistent prices (or corridors) based on switching prices and embedded in complementary regulation.

Advantages?

- Closer in line with precautionary principle
- Shorter analysis horizon
- Systems approach may allow integration of co-benefits

Stiglitz, Stern et al. (2017, p.36, Figure 4)



Source: State and Trends of Carbon Pricing Report (World Bank and Ecofys 2017).

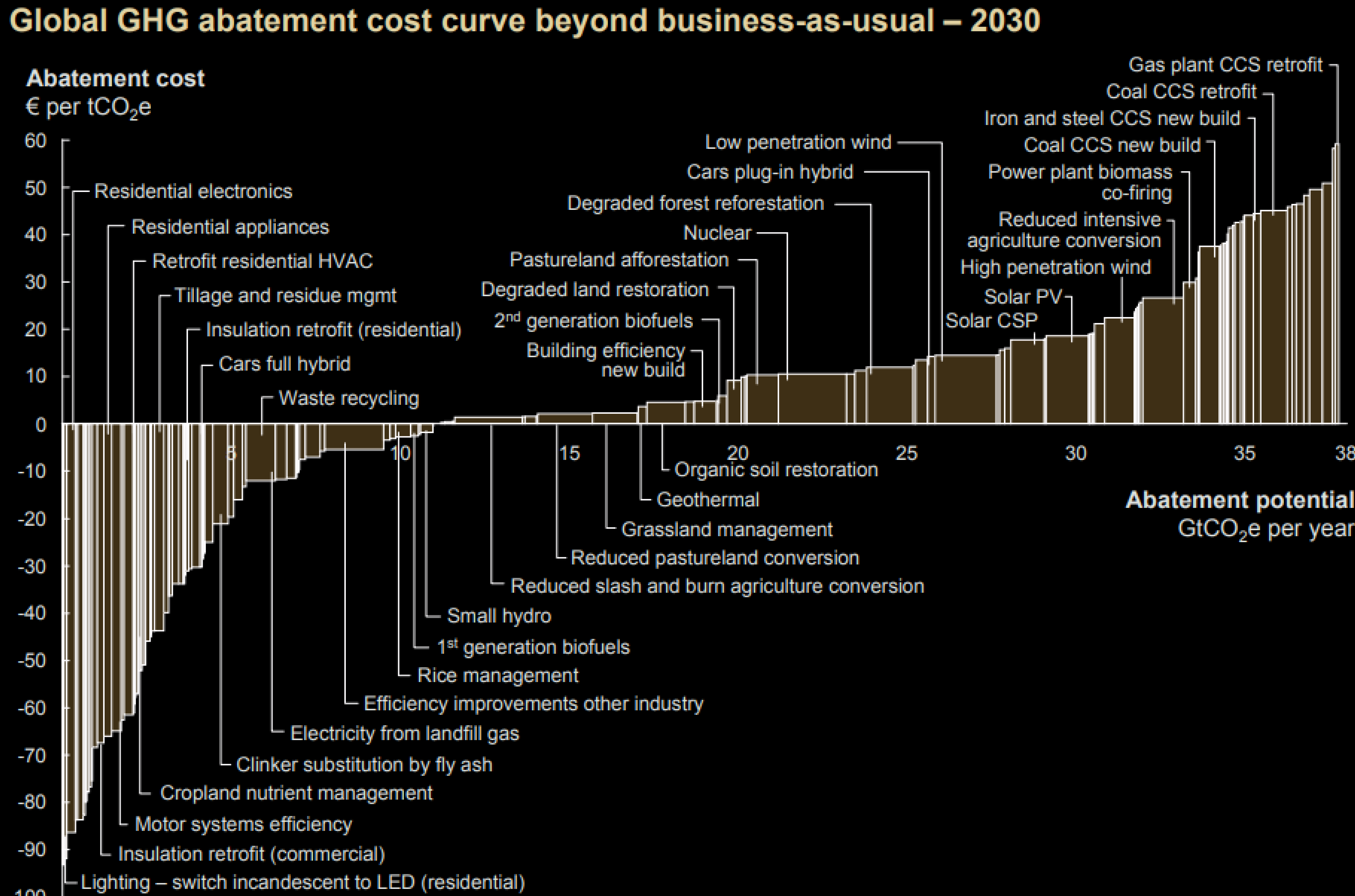
Note: Only the introduction or removal of an ETS or carbon tax is shown. Emissions are presented as a share of global GHG emissions in 2012. Annual changes in global, regional, national, and subnational GHG emissions are not shown in the graph.

- Finland carbon tax
- Sweden carbon tax
- Slovenia carbon tax
- Alberta SGER
- Switzerland carbon tax
- RGGI
- Ireland carbon tax
- California CaT
- Québec CaT
- Shenzhen pilot ETS
- Guangdong pilot ETS
- Mexico carbon tax
- Korea ETS
- Australia ERF (safeguard mechanism)
- Ontario CaT
- Colombia carbon tax
- Poland carbon tax
- Denmark carbon tax
- Estonia carbon tax
- Switzerland ETS
- Liechtenstein carbon tax
- Iceland carbon tax
- Ukraine carbon tax
- Japan carbon tax
- Kazakhstan ETS
- Shanghai pilot ETS
- Tianjin pilot ETS
- Hubei pilot ETS
- Portugal carbon tax
- Fujian pilot ETS
- Alberta carbon tax
- South Africa carbon tax
- Norway carbon tax
- Latvia carbon tax
- EU ETS
- New Zealand ETS
- BC carbon tax
- Tokyo CaT
- Saitama ETS
- Australia CPM
- UK carbon price floor
- Beijing pilot ETS
- France carbon tax
- Chongqing pilot ETS
- BC GGIRCA
- Washington CAR
- Chile carbon tax

Stiglitz et al. (2017, p.35): “85 percent of global emissions are not priced today, and about three quarters of the emissions that are covered by a carbon price are priced below US$10/tCO2e”

Paris-consistent price corridor US$40–80/tCO2 by 2020 and US$50–100/tCO2 by 2030. Stiglitz et al. (2017, p.50): “based on evidence from industry, policy experience, and relevant literature”

Marginal Abatement Cost Curves (MACC)



Note: The curve presents an estimate of the maximum potential of all technical GHG abatement measures below €60 per tCO_2e if each lever was pursued aggressively. It is not a forecast of what role different abatement measures and technologies will play.

Source: Global GHG Abatement Cost Curve v2.0 McKinsey&Company (2013). Pathways to a low-carbon economy

Cost-benefit vs. cost-efficiency analysis

Pitfall of Paris-consistent pricing (Aldy et al. 2021)?

- Takes no account of benefits whatsoever.
  - Benefits are implied, allows for shorter analysis horizon
  - CEA closer in line with precautionary principle (Arrow and Fisher, 1974)
  - Meeting stringent targets is likely cost-effective in long-run (Raihi et al. 2021)
- Political motivation may weaken long-term support
  - SCC adoption is also sensitive to politics; e.g., Trump 7% discount rate
- Inward looking country specific pricing may erode cooperation
  - NDCs and net-zero commitments warrant target-consistent analysis
  - Price corridors may facilitate international agreements
- Assumptions on complementary policies give ranges like SCC
  - Little public support carbon pricing
  - Target-consistent pricing should make trade-offs involved in lowering carbon prices explicit
  - Target-consistent pricing may invite consideration of novel complementary policy

Price corridors may facilitate cooperation

Uniformly mixing, one carbon price

Chancel and Piketty (2015, p.35): "Our results thus corroborate and support the key messages of Chakravarty et al. (2009), for whom all countries should contribute to climate mitigation efforts and emerging countries in particular had to stop "hiding behind their poor" …, given the presence of high emitters in China, India or Brazil."

One price fits all?

Stiglitz, Stern et al. (2017, p.18):

"… there are two (interlinked) reasons why lower-income countries may choose lower carbon prices than high-income countries: (1) low-income countries tend to have less ambitious objectives for emission reductions; and (2) low-income countries tend to require a lower carbon price to achieve a given level of emission reductions."

Little public support for carbon pricing

See Maestre-Andrés et al. (2019)

Ecuador protests 2019

See [Wiki]

Ecuador wanted to cut 1 bn US$ in fossil fuel subsidies:

- Diesel prices doubled, gasoline increased by 30%
- Protest led to state of emergency
- Subsidies were reintroduced

Iran protests 2019/20

See [Wiki]

Iran reduced subsidies on fossil fuel:

- Prices increased by 50% to 300%, but remained among the lowest of the world
- Estimated deaths >1.000

Target-consistent pricing may invite consideration of novel complementary policy

Hickel et al (2022) outline degrowth policy options

Davidson (2019, p.254):

“New scientific findings cataloguing the need for a rapid renewable energy transition are most often met with calls for innovation. Our failure to address climate change and thereby avoid the socioeconomic crises it foretells will not be attributed to a lack of innovation, however, but rather to a lack of exnovation.”

Bełchatów, Poland

MOTHERBOARD
TECH BY VICE

5% of Earth's Power Plants Create 73% of the Energy Sector's Emissions

A handful of "super emitters" are responsible for the vast majority of all emissions in the energy sector.

By Audrey Carleton

Target-consistent approach may allow for integration of co-benefits

Mahecha et al. (2022): study biodiversity – climate change feedbacks

Schmitz et al. (2014): Animating the carbon cycle; e.g., e.g., wildebeest recovery offsets emissions through mitigating fire hazards

Should carbon prices be based on cost-benefit or cost-effectiveness analysis? Are there policy contexts where your answer would differ?

Is there promise to integrate the two?

POLICY LAB

Government as a system

‘Softer’ powers often shared with others

Patterns of action across local, national and international contexts

More ‘formal’ power often associated with governments

Influence	Engage	Design	Develop	Resource	Deliver	Control
1 **Advising** Advising citizens and signposting options to help them find support	2 **Listening** Creating platforms for citizens and stakeholders to protect vested rights and interests.	3 **Connecting** Encourage experts and citizens to co-create change.	4 **Championing** Building a case for change and retain alliances for action.	5 **Charging** Collecting charges for service for example prescriptions, passports or parking.	6 **Nudging** Applying behavioural science or encouraging voluntary codes.	7 **Devolving** Devolving decisions to frontline staff, other authorities or citizens.
8 **Lobbying** Using existing networks and platforms to influence an issue or cause.	9 **Informing** Providing data, sharing knowledge. For example public information advice.	10 **Engaging** Engaging citizens, stakeholders and partners to deliberate on an issue of importance.	11 **Agreeing** Formal agreements e.g. Memoranda of Understanding (MOU).	12 **Incentivising** Promoting behaviour change through grants, subsidies or other incentives.	13 **Educating** Providing materials so citizens know what's available to them.	14 **Providing assurance** Providing assurance / checks and balance on powers.
15 **Agenda setting** Build awareness & confidence in new opportunities by providing thought leadership.	16 **Consulting** Consulting the public or stakeholders on an issue to understand needs and impact.	17 **Analysing** Analysing and interpreting data from local and international contexts.	18 **Partnering** Establishing formal partnerships on an issue of importance to parties.	19 **Contracting** Utilising public procurement to encourage supply chain innovation.	20 **Building** Making infrastructure investments & public commissions e.g. highways.	21 **Licensing** Providing licenses e.g. Taxis, bars & clubs, traders & markets, and health & safety.
22 **Role modelling** Role modelling culture or values through local, national or international presence.	23 **Convening** Drawing together expertise from across system. Including deliberative approaches e.g. citizen juries.	24 **Forecasting** Foresight, horizon scanning and predictive analytics.	25 **Planning** Setting strategy and making plans e.g. Industrial Strategy.	26 **Co-funding** Co-funding activity and pooling budgets with domestic or international partners.	27 **Providing** Delivering services directly or indirectly through funding and target setting.	28 **Regulating** Ensuring regulation enables the intended policy outcomes. Also amending rules, statutory instruments and orders.
29 **Auditing** Auditing and reviewing activities to inform action.	30 **Collaborating** Collaborating with different actors from across the system to deliver outcomes.	31 **Modelling** Modelling different scenarios, shaping and deciding on delivery models.	32 **Commissioning** Commissioning services and outsourcing contracts. Also decommissioning as needed.	33 **Targeting** Utilising initiatives to influence on a particular issue e.g. Cultural programmes	34 **Reforming** Harnessing political will for change to improve outcomes.	35 **Intervening** Making an intervention to correct or improve a market or social context e.g. correcting market failure.
36 **Governing** Establishing governance and setting up formal structures such as boards.	37 **Negotiating** Early engagement on a shared interest or issue including diplomacy.	38 **Testing** Testing, prototyping and learning to establish efficacy of a proposed intervention.	39 **Interpreting** Translating policies across different places and jurisdictions.	40 **Investing** Investing in various forms including Inward investment and foreign direct investment.	41 **Safeguarding** Overseeing the welfare of vulnerable groups.	42 **Enforcing** Support enforcement and harmonise regulatory compliance environment.
43 **Publishing** Publishing plans, priorities, guidance and reviews.	44 **Running elections** Running democratic services and elections.	45 **Piloting** Small scale trials to learn lessons and establish an evidence base for change.	46 **Drafting** Publishing proposals for consultation and pre-legislative scrutiny e.g. white papers and bills.	47 **Funding** Direct finance to stimulate markets or deliver positive outcomes.	48 **Preventing** Intervening early or investing in preventative measures e.g. Public health.	49 **Sanctioning** Putting in place sanctions e.g. embargoes and political trade restrictions.
50 **Scrutinising** Establishing scrutiny committees for example section 15 powers.	51 **Setting standards** Harmonising and setting standards for different stakeholders.	52 **Evaluating** Evaluating efficacy of activities or interventions to establish value for money and impact.	53 **Legislating** (Primary and Secondary) Supporting a bill through parliament and enacting legislation.	54 **Recovering** Recovering debt and other actions to address fraud and error.	55 **Protecting** Protecting consumer rights and supply-chain. Upholding of standards.	56 **Prosecuting** Powers to investigate and prosecute criminal offences e.g. Local Gov Act 1972.

Thank you!

Questions?

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Noah's Ark 2.0

Give \ / a man
a fish \ / and you
feed him \/ for a day,
teach a man to fish and
you
feed him for a lifetime,
preserve the fish stock
and you feed generations.
Dr. J. Sol

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