CLIMATE POLICY AND THE GREEN AGENDA
Could Nordhaus be Right?

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The challenges of climate change present a 'wicked problem' that is difficult to solve because of incomplete, contradictory, and changing requirements. The scale is global, the duration covers many generations into the future, and the uncertainties can seem overwhelming.

"… global warming is a major threat to humans and the natural world." (Nordhaus, 2013, p. 3)

"This is the challenge of our collective lifetimes. The existential threat to human existence as we know it. And every day we delay, the cost of inaction increases." (Biden, 2021)

"Yes, it's true that the globe is warming, and that humans are exerting a warming influence upon it. But beyond that—to paraphrase the classic movie *The Princess Bride*: 'I do not think "The Science' says what you think it says.'" (Koonin, 2021, p. 1)

"The science shows us that fears of a climate apocalypse are unfounded. Global warming is real, but it is not the end of the world. It is a manageable problem." (Lomborg, 2020)

"The #COP26 is over. Here's a brief summary: Blah, blah, blah." (Thunberg, 2021)

"My experience tells me that we need to cool down the rhetoric so that we can understand the underlying issues." (Nordhaus, 2013, p. 15)

The DICE model and its applications by Nordhaus have long been a focal point of a subset of climate policy debates.

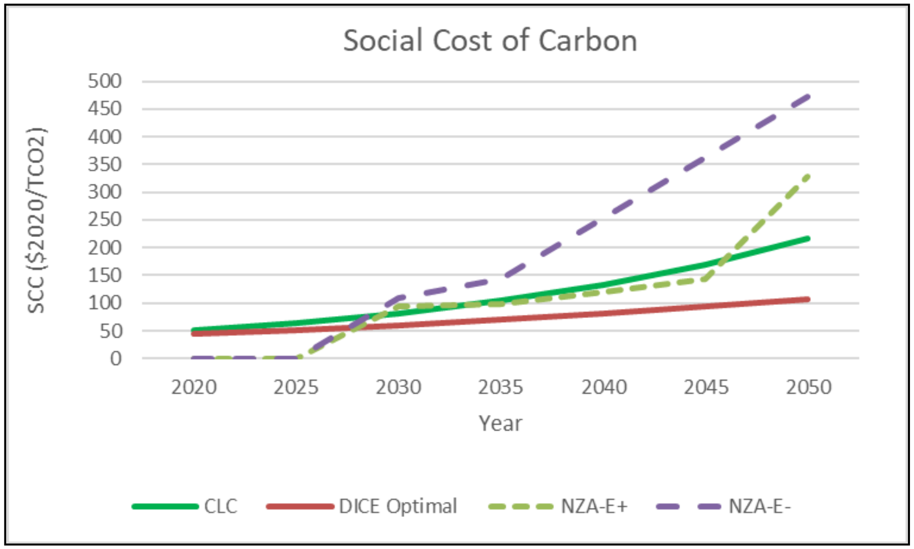
If Nordhaus is right:

- We have delayed, and delayed, and the climate problem is growing.
- Governments are making aspirational promises that they should not, and won't, keep.
- We are doing the wrong things and increasing the costs of mitigation.
- The gaps between the rhetoric and the reality threaten a policy backlash that strikes at the heart of assumed universal participation. This will make everything harder.
- Carbon pricing that incorporates the Social Cost of Carbon is necessary, if we are serious. Critical supplements include innovation support through Research, Development and Demonstration phases (RD&D) with less focus on Deployment (the third "D").
- Adaptation is unavoidable. Research on and a policy for geoengineering are necessary, just in case it is needed.

The focus here is on cost-benefit analysis with an emphasis on the Social Cost of Carbon (SCC) and the related implications for emissions, concentrations and temperatures over centuries and the implications for near-term policies.

Overview

- The Science helps identify the challenges and opportunities.
- The Science does not and cannot tell us what to do.
- There are tradeoffs and this points to the need for cost-benefit analysis.
- One guidepost is the Social Cost of Carbon that provides a standard for what to do and how much is enough.
- There are many critical uncertainties.
- A central problem is the continuing debate about discount rates.



- The climate policy choices will interact with everything else, including the design and operation of energy markets.

MAKING CHOICES

"CLIMATE CHANGE IS ONE OF THE DEFINING ISSUES OF OUR TIME." … From Royal Society and National Academy of Sciences "Climate Change Evidence & Causes, Update 2020." (The Royal Society and National Academy of Sciences, 2020)

From the Forward: "The evidence is clear. However, due to the nature of science, not every detail is ever totally settled or certain. Nor has every pertinent question yet been answered. Scientific evidence continues to be gathered around the world. Some things have become clearer and new insights have emerged. For example, the period of slower warming during the 2000s and early 2010s has ended with a dramatic jump to warmer temperatures between 2014 and 2015. Antarctic sea ice extent, which had been increasing, began to decline in 2014, reaching a record low in 2017 that has persisted. These and other recent observations have been woven into the discussions of the questions addressed in this booklet.

Calls for action are getting louder. The 2020 Global Risks Perception Survey from the World Economic Forum ranked climate change and related environmental issues as the top five global risks likely to occur within the next ten years. Yet, the international community still has far to go in showing increased ambition on mitigation, adaptation, and other ways to tackle climate change."

From the Conclusion: "Citizens and governments can choose among several options (or a mixture of those options) in response to this information: they can change their pattern of energy production and usage in order to limit emissions of greenhouse gases and hence the magnitude of climate changes; they can wait for changes to occur and accept the losses, damage, and suffering that arise; they can adapt to actual and expected changes as much as possible; or they can seek as yet unproven "geoengineering" solutions to counteract some of the climate changes that would otherwise occur. Each of these options has risks, attractions and costs, and what is actually done may be a mixture of these different options. Different nations and communities will vary in their vulnerability and their capacity to adapt. ***There is an important debate to be had about choices among these options***, to decide what is best for each group or nation, and most importantly for the global population as a whole. The options have to be discussed at a global scale because in many cases those communities that are most vulnerable control few of the emissions, either past or future. Our description of the science of climate change, with both its facts and its uncertainties, is offered as a basis to inform that policy debate." (Emphasis added)

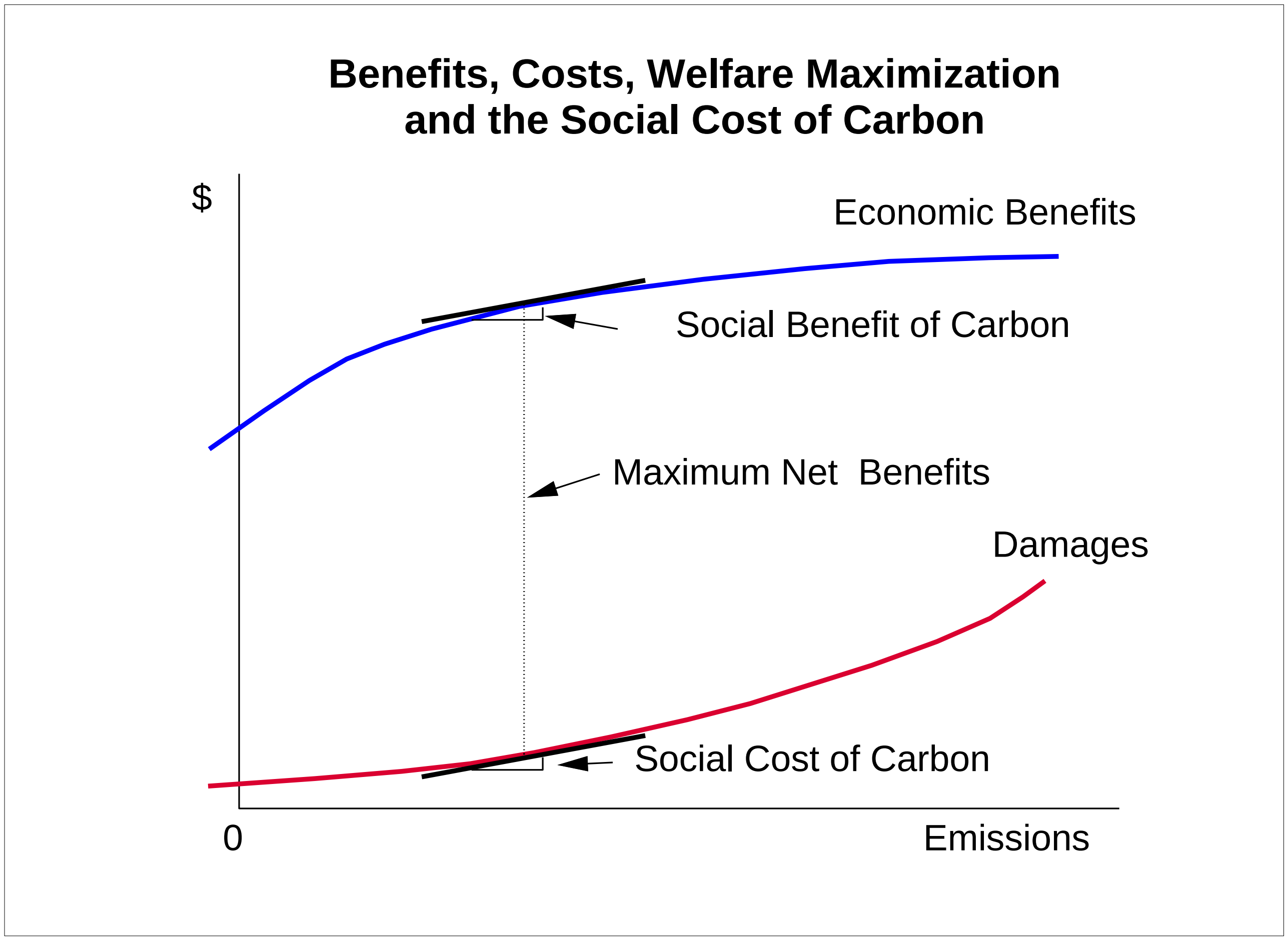
The discussion on international agreements emphasizes targets and related emission trajectories: A maximum of 2ºC or, more recently, 1.5ºC degrees of warming above pre-industrial levels.

"In the Copenhagen Accord, countries recognized 'the scientific view that the increase in global temperature should be below 2 degrees Celsius.' [footnote in original] This was the first time that any climate target had been established at a global conference. The target of limiting climate change to 2°C above preindustrial levels has been widely accepted among governments, scientists, and environmentalists. … Where does this scientific view come from? Was the 2°C target based on a strong body of evidence that suggests there is a threshold at 2°C? Would there be "dangerous" or at least serious consequences if the earth's climate system passes this threshold? The surprising answer is that the scientific rationale for the 2°C target is not really very scientific. … 'Subsequent scientific research has sought to better understand and quantify the links among GHG emissions, atmospheric GHG concentrations, changes in global climate, and the impacts of those changes on human and environmental systems. Based on this research, many policy makers in the international community recognize limiting the increase in global mean surface temperature to 2°C above preindustrial levels as an important benchmark; this goal was embodied in the Copenhagen Accords, at a 2009 meeting of the G-8, and in other policy forums.' [footnote in original] ***So the politicians refer to the science, and the scientists refer to the politics.***" (Nordhaus, 2013, pp. 199–200) (emphasis added)

More on Cost-Benefit analysis and the 1.5ºC warming target:

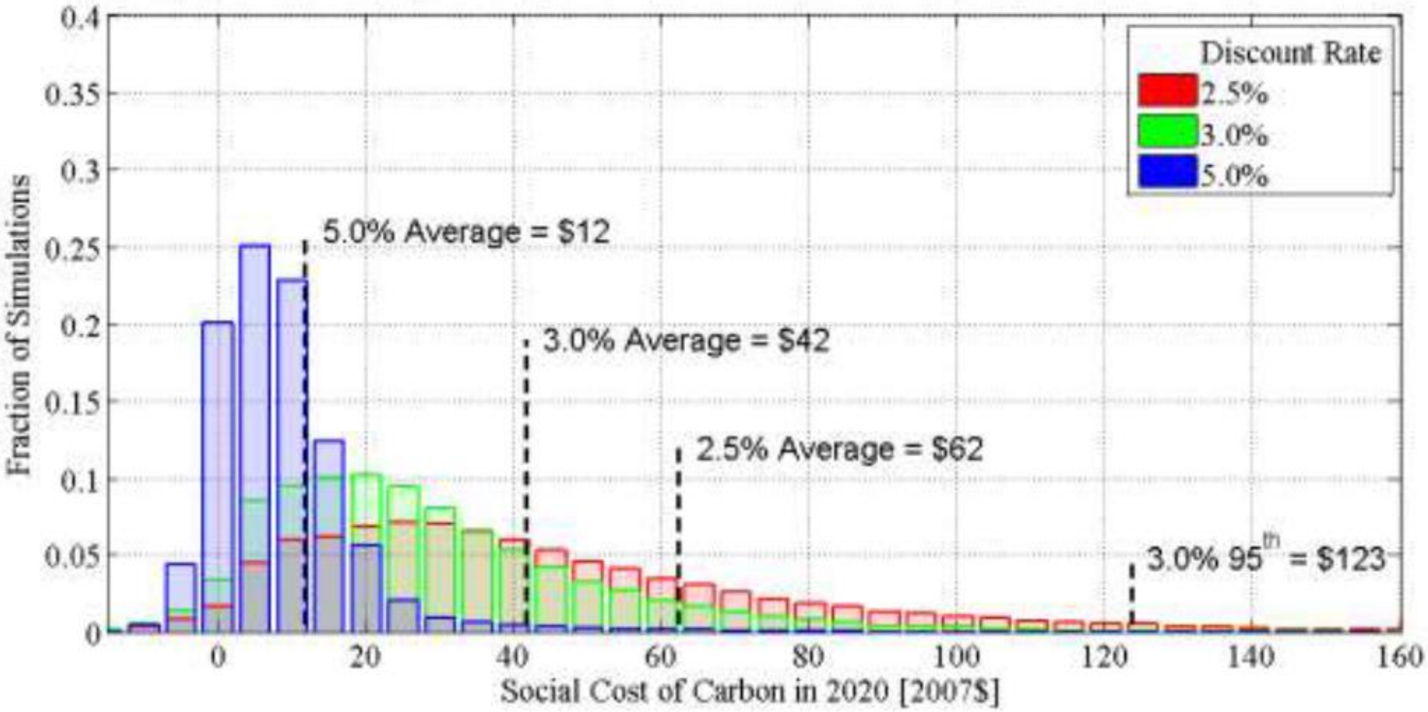
More recently, the Intergovernmental Panel on Climate Change (IPCC) report on the implications of 1.5ºC warming has been cited as recommending the 1.5ºC target (Chen et al., 2021, p. 2715). The IPCC report provides a great deal of interesting and relevant information. However, the cited IPCC reports says: “In its decision on the adoption of the Paris Agreement, the Conference of Parties (COP) to the United Nations Framework Convention on Climate Change (UNFCCC) at its 21st Session in Paris, France (30 November to 11 December 2015), invited the IPCC to provide a special report in 2018 on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways. The Panel accepted the invitation and placed the Report in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty.” (Masson-Delmotte et al., 2018, p. vii). Further, the working group explicitly disavowed any attempt at evaluating the costs and benefits, or even the pros and cons of the target: “Cost–benefit analyses are common tools used for decision-making, whereby the costs of impacts are compared to the benefits from different response actions (IPCC, 2014a, b). However, for the case of climate change, recognising the complex inter-linkages of the Anthropocene, cost–benefit analysis tools can be difficult to use because of disparate impacts versus costs and complex interconnectivity within the global social-ecological system … Some costs are relatively easily quantifiable in monetary terms but not all. Climate change impacts human lives and livelihoods, culture and values, and whole ecosystems. It has unpredictable feedback loops and impacts on other regions (IPCC, 2014a), giving rise to indirect, secondary, tertiary and opportunity costs that are typically extremely difficult to quantify. Monetary quantification is further complicated by the fact that costs and benefits can occur in different regions at very different times, possibly spanning centuries, while it is extremely difficult if not impossible to meaningfully estimate discount rates for future costs and benefits. ***Thus standard cost–benefit analyses become difficult to justify (IPCC, 2014a; Dietz et al., 2016) and are not used as an assessment tool in this report.****”* (Masson-Delmotte et al., 2018, p. 76) (emphasis added). This is far from providing the full story to support a recommendation. Completing the story would require returning to the question of the SCC and the marginal cost of emission reductions.

Higher carbon emissions increase conventional measures of economic benefit but create climate related damages that are not otherwise recognized in private decisions. The Social Cost of Carbon would define the "appropriate price on pollution." Too high or too low would reduce net welfare. (Aldy et al., 2021)



SOCIAL COST OF CARBON

The challenge of climate change and the impact of carbon dioxide and other greenhouse gas emissions is a textbook example of a market failure. The policy implication is to internalize the cost of carbon. The benchmark for the best policy is a carbon tax. Although there is significant uncertainty, the estimates from the U.S. government imply a substantial social cost of carbon dioxide ($/ton CO2) that is not internalized in the market.



Regulatory Impact Analysis - Under Executive Interagency Working Group on Social Cost of Carbon. (2013). Technical Update of the Social Cost of Carbon for Order 12866, (U. S. Government Interagency Working Group on Social Cost of Carbon, 2016)

The Nordhaus DICE model provides a framework and a focal point for climate policy based on cost-benefit analysis.

The DICE model has developed over many years. (Nordhaus, 1992), (Nordhaus, 2008), (Nordhaus & Sztorc, 2013), (Nordhaus, 2013), (Nordhaus, 2017), (Nordhaus, 2018).

A high-level representation of the Dynamic Integrate model of the Climate and the Economy (DICE):

$$(1) \qquad \max_{c(t)} W = \max_{c(t)} \left[\int_0^\infty U[c(t)]\, e^{-\rho t} dt \right]$$

subject to

$$(2) \qquad c(t) = M\big(y(t); z(t); \alpha; \varepsilon(t)\big).$$

“In the equations, 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. This highly simplified representation shows an optimization of the path of consumption in (1) subject to a complex constraint in (2). The most challenging part of constructing the DICE model is to determine the structural constraints in (2).” (Nordhaus, 2019a, p. 1995)

The Nordhaus uncertainty analysis emphasizes the structural constraints in (2). Much of the debate about discount rates centers on the objective function in (1).

The debate over the basic elements of the social cost of carbon is mind numbing. There is a temptation to dismiss the conversations as without a possible resolution.

- **Emission benefits accrue now, and emission costs are in the future.**
- **Seemingly small changes in discount rates have a major impact.**
  - ***Unsettled issues about discount rates for the economy.***
  - ***Discounting requires intergenerational comparisons.***
- **Uncertainty affects everything.**
  - Economic and population growth are uncertain.
  - Technology change rates are uncertain.
  - ***Implied temperature levels are uncertain.***
  - Climate induced damages are uncertain.
  - ***Catastrophic climate effects could be irreversible.***
- Adaptation will be necessary and geoengineering may be a last resort (Felgenhauer et al., 2021) (Belaia et al., 2021).
- **Broad participation will be required to meet a global problem.**

The structure of the DICE model can encompass high or low estimates of the SCC (Dietz & Stern, 2015). The wide range of uncertainty requires some assessment of the probabilities of the parameters and interactions of the effects. This increases the value of a model in organizing a coherent policy and supporting analyses.

Seemingly small changes in discount rates have a major impact on the estimated social cost of carbon.

Estimates for different policies and different discounting assumptions are summarized in (Nordhaus, 2017).

Table 1. Global SCC by different assumptions

Scenario	Assumption	2015	2020	2025	2030	2050
Base parameters						
	Baseline*	31.2	37.3	44.0	51.6	102.5
	Optimal controls†	30.7	36.7	43.5	51.2	103.6
2.5 degree maximum						
	Maximum†	184.4	229.1	284.1	351.0	1,006.2
	Max for 100 y†	106.7	133.1	165.1	203.7	543.3
The Stern Review discounting						
	Uncalibrated†	197.4	266.5	324.6	376.2	629.2
Alternative discount rates*						
	2.5%	128.5	140.0	152.0	164.6	235.7
	3%	79.1	87.3	95.9	104.9	156.6
	4%	36.3	40.9	45.8	51.1	81.7
	5%	19.7	22.6	25.7	29.1	49.2

The SCC is measured in 2010 international US dollars.
*Calculation along the reference path with current policy.
†Calculation along the optimized emissions path.

DISCOUNT RATES

Unsettled issues arise in the analysis of markets and rates of return for the economy.

“The disagreements about the discount rate are not merely arguments about empirical matters; there are major debates about conceptual issues as well. For example, Stern (2008) and Sterner and Persson (2008) [reference in original] argue that the choice of consumption discount rate should be based almost entirely on ethical considerations: there is no need, for example, to ground the consumption discount rate in observed or expected interest rates or in estimates of the opportunity cost of capital. In contrast, Nordhaus maintains that it is critical to base the choice of discount rate in observed behavior — behavior that is reflected in market interest rates. Similarly, some analysts argue that the choice of discount rate is a purely prescriptive issue, while others claim it should be a descriptive question (i.e., empirically based).” (Goulder & Williams, 2012)

- Model Constructs
  - Utility Discount Rate (ρ)
  - Deterministic Consumption Discount Rate (r_D)
  - Risk-Free Discount Rate (r_F)
  - Risky Consumption Discount Rate (r_C)
- Market Results across 17 countries (Barro & Jin, 2021, p. 15)
  - Market Risk-Free Return on Government Bills (r_G) (0.75%/yr.)
  - Market Return on Capital (r_M) (7.90%/yr.)

Application of the Consumption Capital Asset Pricing Model (CCAPM) yields model results that are inconsistent with market outcomes, with $r_C < r_M$ and $r_C - r_F < r_M - r_G$.

This is the unsettled equity premium puzzle (Mehra, 2012) (Dietz et al., 2018) (Barro & Jin, 2021).

The Nordhaus Dynamic Integrated Climate-Economy (DICE) model applies a deterministic optimal growth framework, derived from a standard expected utility objective function. (Nordhaus, 2018)

$$W = \sum_{t=1}^{T_{MAX}} \frac{1}{(1+\rho)^t} \frac{c(t)^{1-\alpha}}{1-\alpha} L(t)$$

where

$c(t)$	Per Capita Consumption
$L(t)$	Population
ρ	Utility Discount Rate

The parameter (α) is interpreted as the generational inequality aversion. For example, in the DICE-2016 model per capita consumption in 2100 is 4.4 times the 2020 level. With $\alpha = 1.45$, the undiscounted per capita tradeoff has an \$8.59 decrease in consumption in 2100 indifferent to a \$1 increase in 2020.

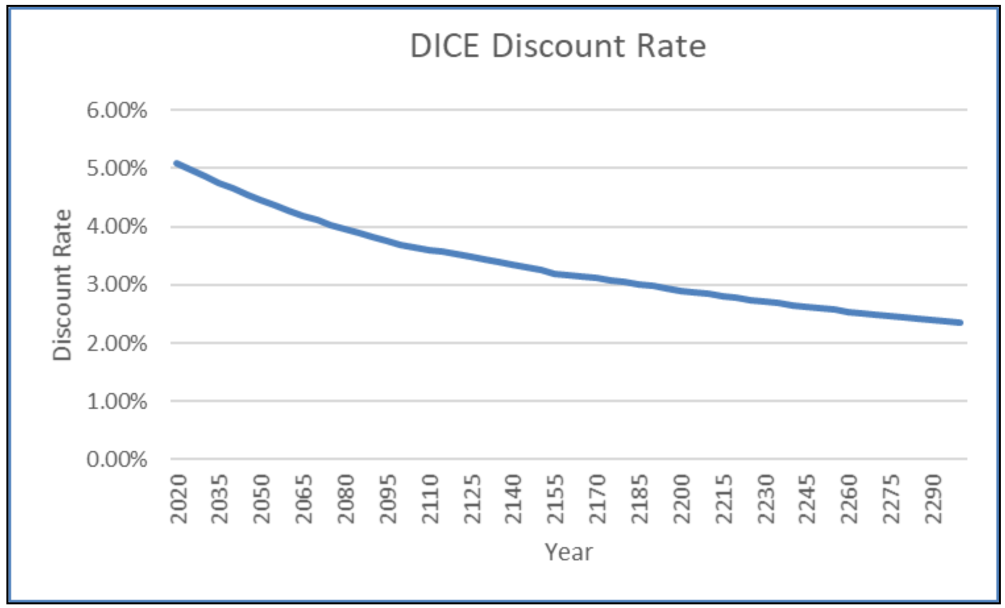
The DICE model is based on expected values (no uncertainty). Hence the discount rate on goods is the same as the risk-free rate determined as a function of the utility discount rate ($\rho = 1.5\%$), inequality aversion, and the economic growth rate (g) according to a version of the Ramsey rule:

$$r_D = \rho + \alpha g.$$

The model parameters are chosen to make the endogenous social welfare discount rate in a deterministic model more consistent with the "discount rate in observed behavior." ($r_{SW} \approx r_D \approx r_C \approx r_M$)

Arguably the DICE discount rates for the globe are too low relative to the empirical observations:

$$r_M = 7.90\%.$$



An alternative to the additive utility model in DICE is the recursive Epstein-Zin utility function (Kreps & Porteus, 1978) (Epstein & Zin, 1989) (Weil, 1990). **This introduces a new parameter and allows a different characterization of risk aversion and intertemporal substitution** (Barro & Jin, 2021) (Daniel et al., 2019)**.**

A core element of the objective function is per capita utility as:

$$U_t = \left[(1-\beta) c_t^{1-\alpha} + \beta \left(E_t \left[U_{t+1}^{1-\theta} \right] \right)^{1-\alpha / 1-\theta} \right]^{1 / 1-\alpha}.$$

The discount factor is ($\beta = (1+\rho)^{-1}$) and the application has corresponding adjustments for population growth. However, a key feature is the separate treatment of contemporaneous relative risk aversion (θ) and intertemporal substitution parameters (α). Small values of (α) produce high values of the elasticity of intertemporal substitution (EIS=α^{-1}) and much lower discount rates.

Applications illustrate that the separate EIS assumption is critical. For example, (Ackerman et al., 2013) address Roe-Baker Equilibrium Climate Sensitivity (ECS) uncertainty and assumes an EIS=1.5, which increases initial SCC by over 400%. In (Cai & Lontzek, 2019) Roe-Baker ECS uncertainty is not addressed, but multiple tipping point analysis raises the initial SCC by over 600%. The support for EIS=1.5 cites (Pindyck & Wang, 2013). However, Pindyck and Wang emphasize the inability to separately identify the EIS and the pure rate of time preference (ρ). The utility rate of pure time preference in (Pindyck & Wang, 2013, p. 319) is 4.98%, compared to the use of the DICE value of 1.5%. By comparison, (Cai & Lontzek, 2019) incorporates uncertainty in economic growth, and separate analysis that includes stochastic tipping points, and finds the SCC is driven by the EIS assumption. With an EIS comparable to the DICE model (EIS=$(1.45)^{-1} = 0.69$), the SCC results are much closer to DICE (Ackerman et al., 2013, p. 79) (Cai & Lontzek, 2019, p. 2712).

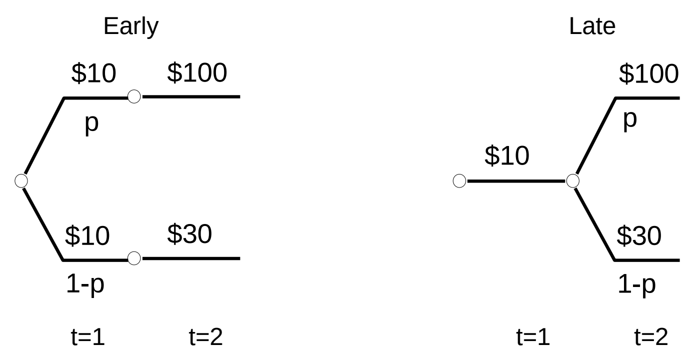
The recursive Epstein-Zin utility function provides flexibility in representing intertemporal tradeoffs. However, this comes at a cost for its use in climate integrated assessment models.

The basic structure of the E-Z utility function creates a premium for early resolution of uncertainty (ERU) when $\theta > \alpha$. (Gollier & Kihlstrom, 2016)

For two different representations of uncertainty with identical payoffs, early resolution is preferred to later resolution. The impacts can be significant:

"Would you give up 25 or 30 percent of your lifetime consumption in order to have all risk resolved next month? … Though risk aversion and the elasticity of intertemporal substitution have been the subjects of careful scrutiny when calibrating preferences, the long-run risks literature and the broader literature using recursive utility to address asset pricing puzzles have ignored the full implications of their parameter specifications. … (this) ***inflates timing premia to levels that seem implausible***." (Epstein et al., 2014) (emphasis added)

Epstein-Zin Early Resolution of Uncertainty



CE($110,$40,p)>$10+CE($100,$30,p)

Early Resolution Preferred Despite
No Decisions and Same Expected Payoffs

Without the embedded timing premium, in the case with $\theta = \alpha$, or when there is independent uncertainty, or for the special case of deterministic consumption, the EZ model returns to the same structure as the utility function in DICE (Gollier & Kihlstrom, 2016, p. 7); "…under the Rawlsian veil of ignorance, the level of inequality aversion should be equal to the degree of relative risk aversion of the representative consumer, thereby transforming an ethical parameter into a descriptive one." (Gollier & Hammitt, 2014, p. 279)

For the DICE utility function, the uncertainty model changes the implied discount rates.

For simplicity, consider the case of per capita welfare:

$$\hat{W} = E\left[\sum_{t=1}^{\infty} \frac{1}{(1+\rho)^t} \frac{c(t)^{1-\alpha}}{1-\alpha}\right].$$

In the case of certainty, the deterministic rate is a function of the utility discount rate (ρ), the measure of inequality aversion (α), and the growth rate of consumption (g). The deterministic discount rate is:

$$r_D = \rho + \alpha g.$$

Following (Dietz et al., 2018, p. 260), assume the growth rate is uncertain but independent, with $\ln\left(c_t / c_0\right) \sim N\left(\mu t, \sigma^2 t\right)$, and benefit ($B_t$) is correlated with consumption $E\left[B_t \,|\, c_t\right] = c_t^{\beta_t}$.

Then the risk-free rate becomes:

$$r_F = \rho + \alpha\mu - 0.5\alpha^2\sigma^2.$$

The risk premium is $\pi = \alpha\sigma^2$, and the risk-adjusted discount rate becomes:

$$r_t = r_F + \beta_t \alpha \sigma^2.$$

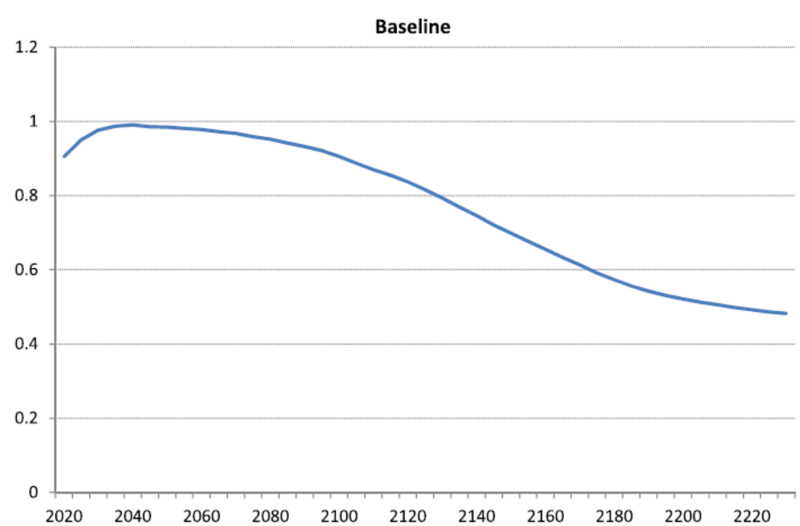
The correlation of climate benefits and uncertain future economic activity is a key element in determining the appropriate discount rate.

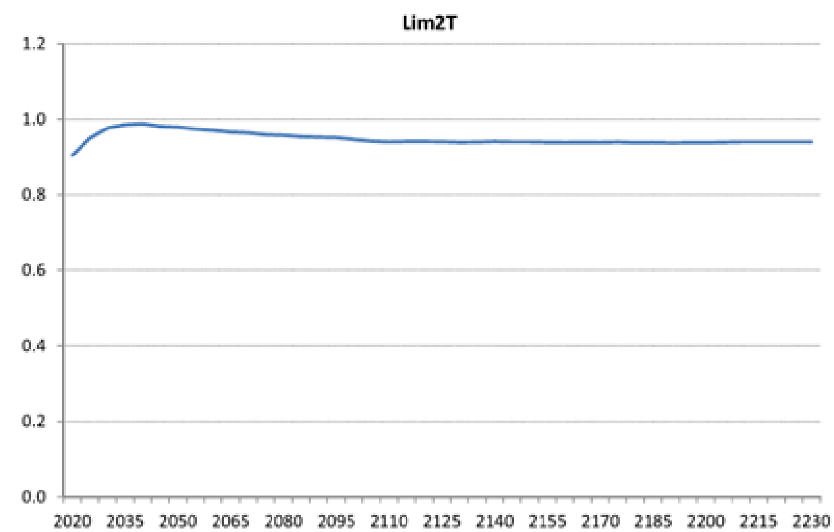
Note that this impact of uncertain economic activity is distinct from the effect of uncertain discount rates as in (Gollier & Weitzman, 2010), which can be addressed through Monte Carlo analysis discussed later.

Given a reference consumption projection and benefits of mitigation (B_t), the focus is on the climate beta:

$$\beta_t = \frac{\operatorname{cov}\left(\ln c_t^{REF}, \ln B_t\right)}{\operatorname{var}\left(\ln c_t^{REF}\right)}.$$

Using a calibration with ten different uncertainties, (Dietz et al., 2018) apply DICE to calculate the implied climate betas for two different reference trajectories, a baseline and a trajectory restricting the temperature increase to 2ºC. For the early baseline and the full stringent climate policy, the climate beta is essentially equal to one.





With a climate beta of one, the debate over discount rates narrows.

The cost of ignoring beta and the risky discount rate is substantial. For example, in a model of heterogenous investments with different underlying betas, (Gollier, 2021) expands the characterization of uncertainty to include long-run risks and rare events (i.e., depressions) as in (Barro & Jin, 2021) while maintaining the objective function of the DICE model. Gollier calibrates using ($\alpha = 3, \rho = 0.01$) to illustrate: "The risk-free discount rate and the aggregate risk premium are respectively equal to 0.86% and 2.22%, which are close to their historical averages over the last century in the United States." (Gollier, 2021, p. 9) The analysis illustrates the costs of ignoring the different betas for different investments. For example, when using a single average discount rate "[t]he bottom line is a massive 27% reduction in the measure of intertemporal welfare." (Gollier, 2021, pp. 12–13).

"One of the most puzzling feature [sic] of the experts' debate on the public discount rate is its reliance on its misleading cornerstone, the Ramsey rule. This rule, adjusted for the uncertainty affecting economic growth, provides the right basis to estimate the rate at which risk-free benefits and costs should be discounted. Using that rule to recommend an all-purpose discount rate in the economy does not only represent a very dangerous interpretation of the theory, as explained in this paper. It also makes it impossible to initiate a constructive debate about how to value the future. As long as one ignores the necessity to adjust discount rates to risk characteristics, all sorts of difficulties materialize, from the WACC fallacy to the rationing of public investments with a positive NPV. ***Over the last ten years, the remarkable stalemate prevailing in the Stern/Nordhaus debate on the social cost of carbon is another vivid illustration of our collective inability to transform our consensual asset pricing theory into practical evaluation rules****.* The impossibility for the U.S. administration to revise its deeply flawed discounting system is a puzzle, in particular given the effort of some prominent experts to change that system (Arrow et al. (2013), Lucas (2014), Sunstein (2014), [references in original]). The social cost of this failure is huge, and the credibility of our profession is at stake given the ability of lobbies and politicians to play with the current inefficient rules. In the U.S., this means updating Circular A-4." (Gollier, 2021, pp. 17–18) (emphasis added).

Addressing the climate beta allows a partial recharacterization of the debate on discount rates.

The target problem is a stochastic dynamic optimization problem. This is difficult to solve and understand (Cai & Lontzek, 2019), (Cai, 2020) (Van den Bremer & Van der Ploeg, 2021), and results with a higher SCC than for DICE hinge on the use of E-Z utility. The DICE model is deterministic, more transparent and utilizes an additive utility function.

With a beta of one, the risk adjusted discount rate for consumption and for climate damages would be the same. An objective is that the DICE model replicates the expected trajectory of a more complete stochastic model using the expected values of the key parameters (Nordhaus, 2018, p. 341) (Nordhaus, 2019a, p. 2006).

Hence:

$$r_D = \rho + \alpha g \approx r_C = r_F + \beta\pi \overset{?}{\approx} r_M .$$

This is true for both the prescriptive and, for the final step, for the descriptive perspectives. The prescriptive approach as in (Stern, 2007) has focused on risk-free rate (r_F) without corresponding attention to the consumption/climate beta and risk premium ($\beta\pi$). See also (National Academy of Sciences, 2017) (Carleton & Greenstone, 2021). The prescriptive approach rejects the relevance of the "equity premium" puzzle (Stern & Stiglitz, 2021), and the implied low discount rates create a range of other problems (Gollier, 2021) (Nordhaus, 2008, Chapter 9).

The equity premium puzzle has not been resolved, and there are many possible explanations of the impacts that would apply to approximation in a deterministic optimization model like DICE.

A stochastic optimization model requires an endogenous characterization of the economic uncertainty (van der Ploeg, 2021). In addition, the empirical data for rates of return could be influenced by a long list of frictions such as taxes and various market imperfections (Mehra, 2012) (Gollier & Mahul, 2017) (Wilson, 2020) (Li & Pizer, 2021).

DICE and related Ramsey type optimization models are deterministic and frictionless. Let (ω, τ) serve as proxies for the missing effects of uncertainty and transaction frictions, respectively. Let $\hat{\rho}$ be the true utility discount rate. Then we could characterize the descriptive model approximation as seeking discount rates such that:

$$r_D = \hat{\rho} + \alpha g + \omega \approx r_C < r_C + \tau = r_M .$$

The risk characteristics for both (β) and unmodeled stochastic risks would be captured by (ω), and the missing frictions (τ) would be interpreted as accounting for the difference between the modeled consumption discount rate (r_C) and the observed risky market return (r_M).

The descriptive approach adopted in DICE in effect uses the two preference parameters (ρ, α) to approximate the risk-adjusted consumption discount rate (Nordhaus, 2014, p. 280). The key easily adjustable parameter is the utility discount rate ($\rho = \hat{\rho} + \omega$) which allows for plausible values for inequality aversion (α) while matching the "prescriptive" or "descriptive" consumption discount rate, all without claiming that the deterministic model discount rate is the same as the risk free rate ($r_D \neq r_F$) or that economic risk does not matter.

Estimating the coefficient of inequality aversion (α) for application in the DICE model.

Based on recommendations for (National Academy of Sciences, 2017) for better estimates of discount rates, (Newell et al., 2021) examines a methodology for combining econometric forecasts of interest rates and economic growth to estimate the parameters of the DICE objective function and a term structure for discount rates. The focus is on the risk-free rate and the parameters (ρ,α).

The framework employs the deterministic DICE discount rate formulation:

$$r_{Dt} = r_{Ft} = \rho + \alpha g_t .$$

An implicit assumption is that the observed market risk-free is rate not affected by the anticipated structure of uncertainty. However, as in (Dietz et al., 2018, p. 260), with a lognormal distribution and a mean growth rate of (μ), the risk-free rate is determined by:

$$r_F = \rho + \alpha\mu - 0.5\alpha^2\sigma^2$$

The numerical difference is small but important conceptually as it is closely connected to the large unexplained equity premium and the implied value for risky consumption and climate damages (r_C).

The estimates In (Newell et al., 2021, p. 15) are conditioned on an initial period constraint. With a 3% starting point, the preferred case estimate has:

$$\rho = 0.8\%, \alpha = 1.53$$

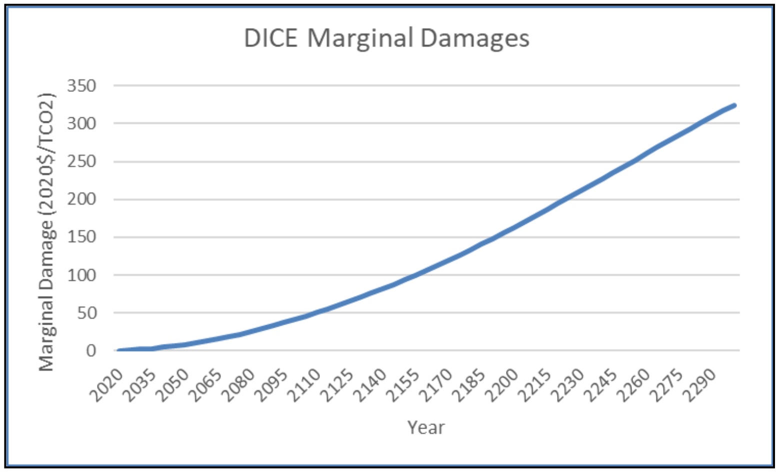
By comparison the most recent DICE model assumption applies

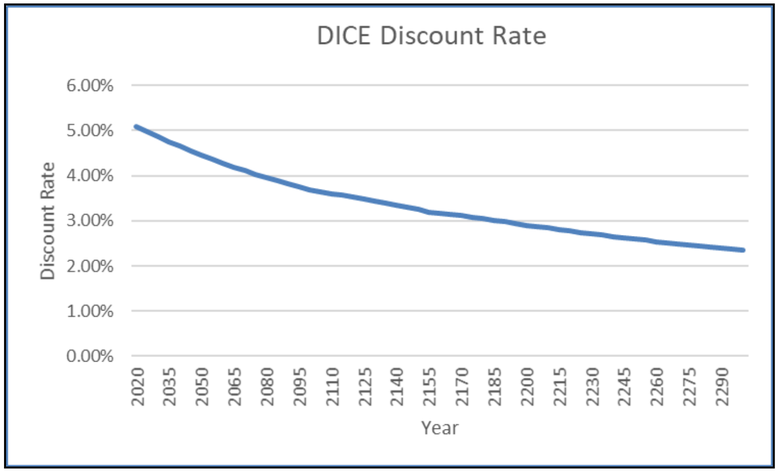
$$\rho = 1.5\%, \alpha = 1.45$$

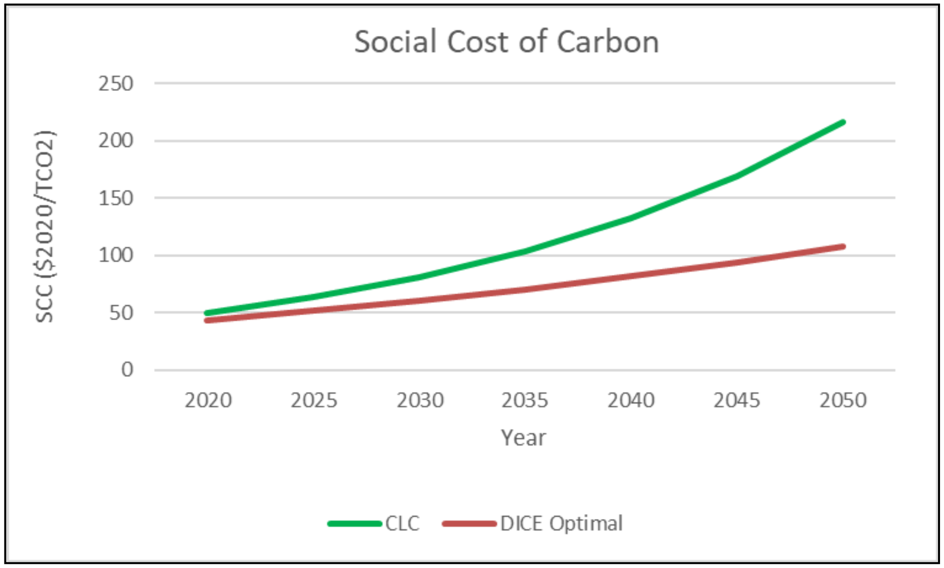
and is more closely connected to the risk adjusted rate (r_C) (Nordhaus & Sztorc, 2013, pp. 37–38) (Nordhaus, 2018, p. 336).

This leads back to the DICE formulation and the calculation of the SCC.

The discount rate combines with the marginal damages from an additional CO2 emission to produce the SCC. Here the DICE optimal case is compared with the Climate Leadership Council (CLC) proposal.







UNCERTAINTY AND THE SCC

The DICE model is deterministic. Nordhaus examined some of the effects of uncertainty in terms of the implied SCC today by approximating the impact of uncertainty in the DICE model.

“When uncertainties are accounted for, the expected values of most of the major geophysical variables, such as temperature, are largely unchanged. However, the social cost of carbon is higher (by about 10 percent) under uncertainty than in the best-guess case because of the asymmetry in the impacts of uncertainty on the damages from climate change. … the relative uncertainty is much higher for economic variables than for geophysical variables.” (Nordhaus, 2018, p. 335)

“The ranges of uncertainty for future emissions, concentrations, temperature, and damages are extremely large. However, this does not reduce the urgency of taking strong climate change policies today. When taking uncertainties into account, the desirable strength of policy (as measured by the social cost of carbon or the optimal carbon tax) would increase, not decrease.” (Nordhaus, 2018, p. 335)

“The act-then-learn approach to decisions cannot be fully incorporated into the current DICE uncertainty structure. … I have undertaken a small test case which examines the impact of learning that is delayed until 2050. …. The results of this simplified example indicate that policies are relatively insensitive to late learning, although there is substantial value of learning. The optimal carbon price in the act-then-learn approach is about 6 percent higher than for that of learn-then-act ($36.1/tCO2 rather than $34.2/tCO2 in 2015.” (Nordhaus, 2018, p. 358)

The Equilibrium Climate Sensitivity (ECS) measures the equilibrium change in temperature from a doubling of carbon concentrations. The reported uncertainty has not changed much in three decades.

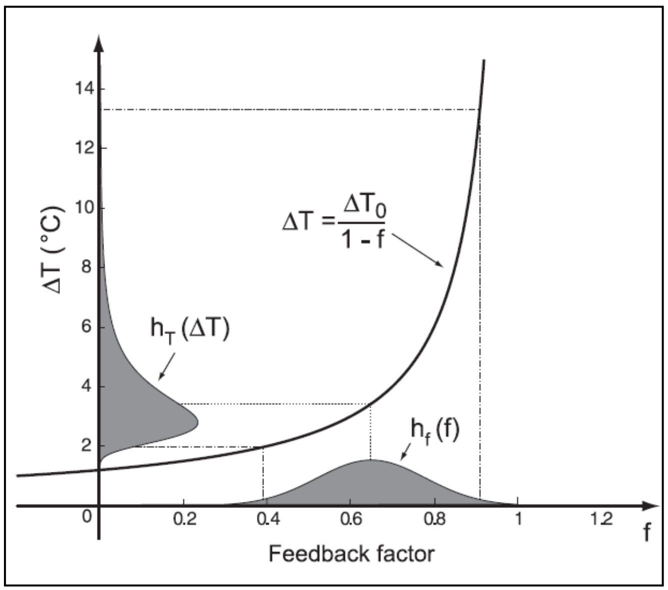
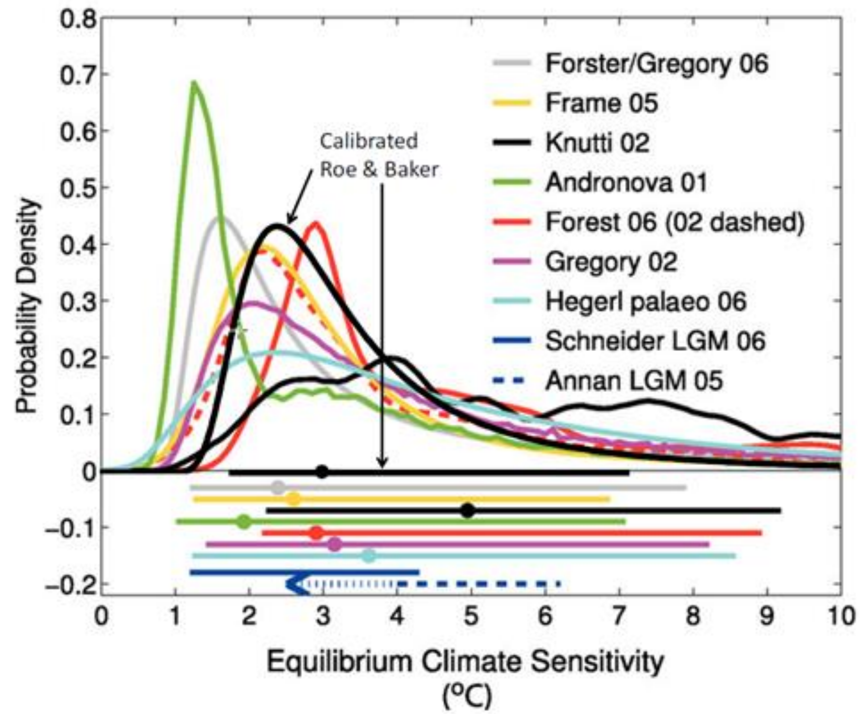


Figure 2: Estimates of the Probability Density Function for Equilibrium Climate Sensitivity (°C)

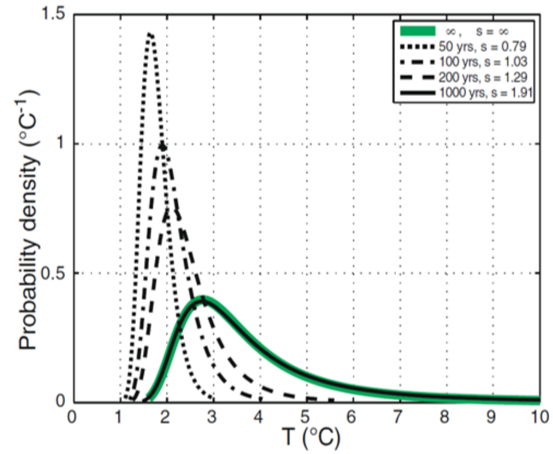


The basic equilibrium theory is found in (Roe & Baker, 2007). The various model representations are found in (Meinshausen et al., 2009). The colored graphic is from (U. S. Government Interagency Working Group on Social Cost of Carbon, 2010)

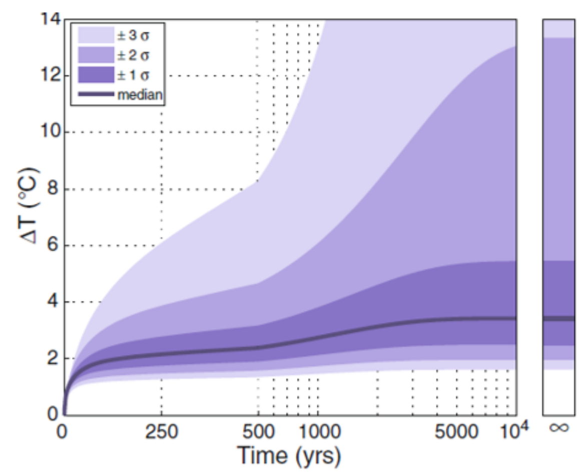
The larger the estimated climate sensitivity, the longer it takes to arrive at the temperature change.
"Should the climate tail wag the policy dog?" (Roe & Bauman, 2013) (emphasis added)

"Economic models that include a climate component, and particularly those that focus on the tails of the probability distributions, should properly represent the physics of this slow response to high climate sensitivity, ***including the correlated uncertainty between present forcing and climate sensitivity***, and the global energetics of the present climate state. If climate sensitivity in fact proves to be high, these considerations prevent the high temperatures in the fat tail from being reached for many centuries. A failure to include these factors risks distorting the resulting economic analyses." (Roe & Bauman, 2013, p. 647)

"**Fig. 2 b** The shape of the [climate sensitivity] distribution at particular times. The skewness of the distributions are also shown in the legend; as described in the text, **the upper bound on possible temperatures is finite at finite time, limiting the skewness**" (Roe & Bauman, 2013, p. 651)

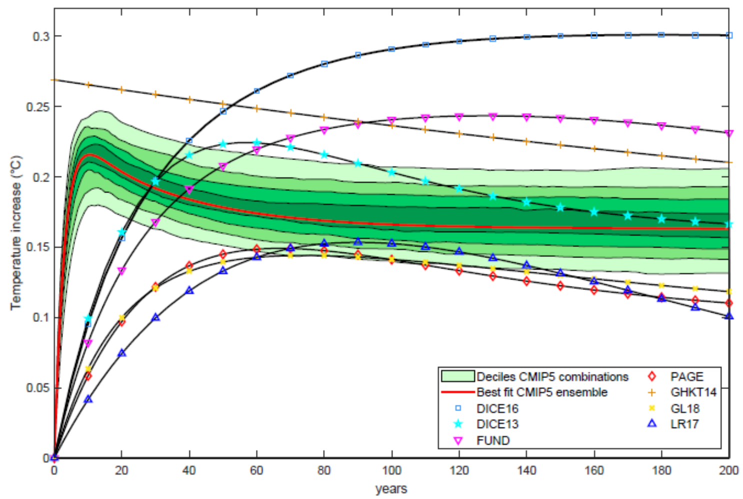


"**Fig. 2 a** The time evolution of uncertainty in global temperature in response to an instantaneous doubling of CO_2 at t = 0, and for standard parameters. The shading reflects the range of feedbacks considered (symmetric in feedbacks, but not in climate response), as explained in the text. Note the change to a logarithmic x-axis after t = 500 yr. The panel illustrates that **for high climate sensitivity it takes a very long time to come to equilibrium**." (Roe & Bauman, 2013, p. 651)



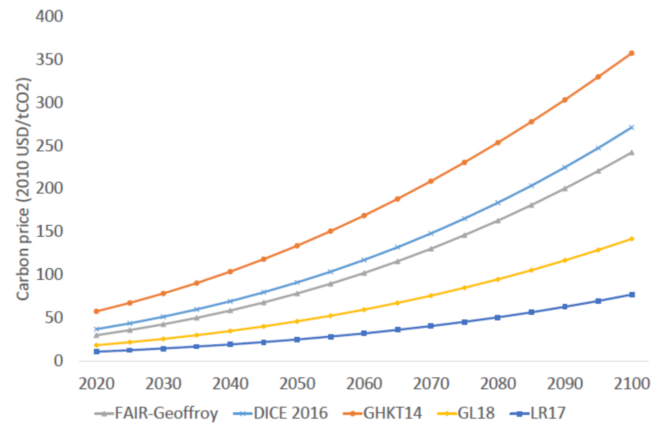
The net effect of the timing correlation is to substantially moderate the impact of high damages on the present social cost of carbon.

The trajectory of temperature effects, presents a related uncertainty that interacts with the discount rate in determining the SCC.

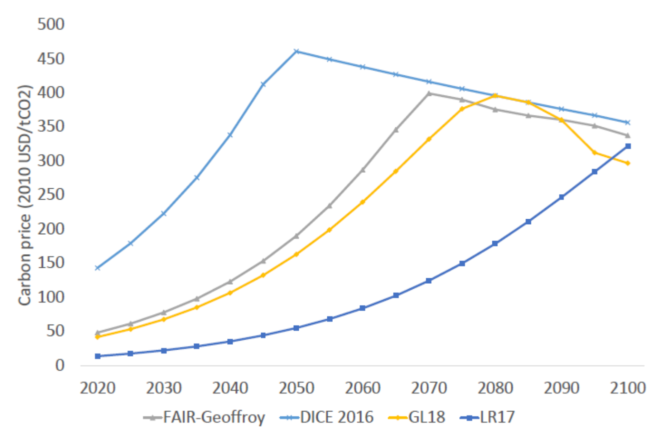


The Integrated Assessment Models (IAMs), including DICE incorporate climate dynamics that differ from an ensemble of 256 more recent climate models. A modified version of DICE fitted to the climate models produces similar optimized SCC values. The authors find "...an initial carbon price of $30 in the benchmark DICE-FAIR-Geoffroy model and $37 in standard DICE 2016." (Dietz, van der Ploeg, et al., 2021, p. 909) By contrast, the temperature timing produces different results for the implied cost of a 2º warming constraint.

Welfare maximising carbon prices



2°C cost-minimising carbon prices



Climate catastrophic effects that might be irreversible are part of active investigation. As with the climate sensitivity, there an uncertain likelihood and the timing may be far in the future.

The Gulf Stream: "Results from the best available climate models do not predict an abrupt change in (or collapse of) the Atlantic Meridional Overturning Circulation, … . Some abrupt changes are already underway, such as the decrease in Arctic sea ice extent …, and as warming increases, the possibility of other major abrupt changes cannot be ruled out." (The Royal Society and National Academy of Sciences, 2020)

The Greenland Ice Sheet: "Concerns about the impact on large-scale earth systems have taken center stage in the scientific and economic analysis of climate change. The present study analyzes the economic impact of a potential disintegration of the Greenland ice sheet (GIS). … The study demonstrates that social cost–benefit analysis and damage-limiting strategies can be usefully extended to illuminate issues with major long-term consequences, as well as concerns such as potential tipping points, irreversibility, and hysteresis. A key finding is that, under a wide range of assumptions, the risk of GIS disintegration makes a small contribution to the optimal stringency of current policy or to the overall social cost of climate change."

Table 2. Social cost of carbon

Scenario	SCC, 2015; 2011$/t$CO_2$	Percent of total SCC, %
Both damages	31.39	
Normal damages only	31.23	99.6
GIS damages only	0.13	0.4
Sum of two individual	31.36	

GIS damages are a small percent of the total. These calculations use a 1,000-y time horizon, but using a 2,000-y horizon makes little difference.

(Nordhaus, 2019b)

The net effect is to substantially moderate the impact on the present social cost of carbon.

There are many possible tipping points that could be important. However, they are similar to the Greenland Ice Sheet in that the distant timing and high uncertainty imply a relatively small effect on the initial SCC and the recommended stringency of climates polices.

"Collectively, climate tipping points increase the social cost of carbon (SCC) by ~25% in our main specification. … We synthesize this emerging literature and provide unified, geophysically realistic estimates of the economic impacts of eight climate tipping points with an emphasis on the social cost of carbon, a key policy input." (Dietz, Rising, et al., 2021, p. 1)

Table 2. The SCC (2020 US dollars) and the percentage change in the SCC due to tipping points collectively and individually

TP	Expected SCC, US\$/tCO_2	Increase due to TP, %
None	52.03	—
Permafrost carbon	56.41	8.4
Ocean methane hydrates	58.85	13.1
SAF	51.14	−1.7
Amazon	52.07	0.1
GIS	52.97	1.8
WAIS	53.57	2.9
AMOC	51.28	−1.4
Indian summer monsoon	52.70	1.3
All TPs	64.80	24.5
∑ main effects, all TPs	—	24.5
All costly TPs	67.05	28.9
∑ main effects, costly TPs only	—	27.6

The expected SCC is computed over 10,000 Monte Carlo draws with 0.1% trimmed. Specification comprises RCP4.5-SSP2 emissions and GDP/population growth, Hope and Schaefer PCF, Whiteman et al. beta OMH, and IPSL AMOC hosing. TP, tipping point.

(Dietz, Rising, et al., 2021, p. 3)

By way of comparison: "…current studies generally omit several important factors (the economic value of losses from biodiversity, ocean acidification, and political reactions), extreme events (sea-level rise, changes in ocean circulation, and accelerated climate change), impacts that are inherently difficult to model (catastrophic events and very long-term warming), and uncertainty (of virtually all components from economic growth to damages). I have added an adjustment of 25 percent of the monetized damages to reflect these non-monetized impacts." (Nordhaus & Sztorc, 2013, p. 11).

CLIMATE POLICY

The NAS identified two main barriers and emphasized two "overarching recommendations." (National Academy of Sciences, *The Power of Change: Innovation for Development and Deployment of Increasingly Clean Electric Power Technologies*, Washington D.C., 2016, pp.3-4.) (National Academy of Sciences, 2016)

Barriers

"The committee concluded that there are two significant barriers to accelerating greater penetration of increasingly clean electricity technologies. First, as noted above, the market prices for electricity do not include "hidden" costs from pollution, stemming mainly from negative impacts on human health, agriculture, and the environment. Levels of criteria pollutants declined over the past three decades, but still cause harms. Harms from GHGs are difficult to estimate, but if accounted for in the market, could be considered by consumers. …

The second barrier is that the scale of the climate change challenge is so large that it necessitates a significant switch to increasingly clean power sources. In most of the United States, however, even with a price on pollution, most increasingly clean technologies would lack cost and performance profiles that would result in the levels of adoption required. In most cases, their levelized costs are higher than those of dirtier technologies, and there are significant challenges and costs entailed in integrating them into the grid at high levels. This means that reducing the harmful effects of emissions due to electricity generation will require a broader range of low-cost, low- and zero-emission energy options than is currently available, as well as significant changes to the technologies and functionality of the electricity grid and the roles of utilities, regulators, and third parties. …

…even if the technological and institutional barriers to greater adoption of increasingly clean power technologies were overcome but their prices were not competitive, an adequate scale of deployment would require tremendous public outlays, and in many parts of the world would be unlikely to occur. While learning by doing can lower some costs, deployment incentives are likely to be insufficient as the primary policy mechanism for achieving timely cost and performance improvements."

The NAS identified emphasized two "overarching recommendations." (National Academy of Sciences, 2016)

Recommendations

"The U.S. federal government and state governments should significantly increase their emphasis on supporting innovation in increasingly clean electric power generation technologies.

Simply put, the best way to encourage market uptake is first to have technologies with competitive cost and performance profiles. The need for increased innovation and expanded technology options is especially important given the global picture. In many parts of the world, coal remains the cheapest fuel for electricity generation. China, India, and the nations of Southeast Asia are expected to continue rapidly adding new electricity generation facilities, most of them coal-fired and with minimal pollution controls. Thus there is a need for technological innovations that are affordable outside the United States as well. These improvements in performance and cost will be essential to achieve long-term GHG reductions, such as the reduction called for in the COP21 agreement, without significantly increasing electricity prices. …"

This addresses the usual ***Research, Development and Demonstration (RD&D)*** market failure and identifies a target for government action. The need for expanded RD&D is widely recognized, from The National Academies to Bill Gates.

The NAS offered a second recommendation which addresses the third "D" of deployment. (National Academy of Sciences, 2016)

Recommendations

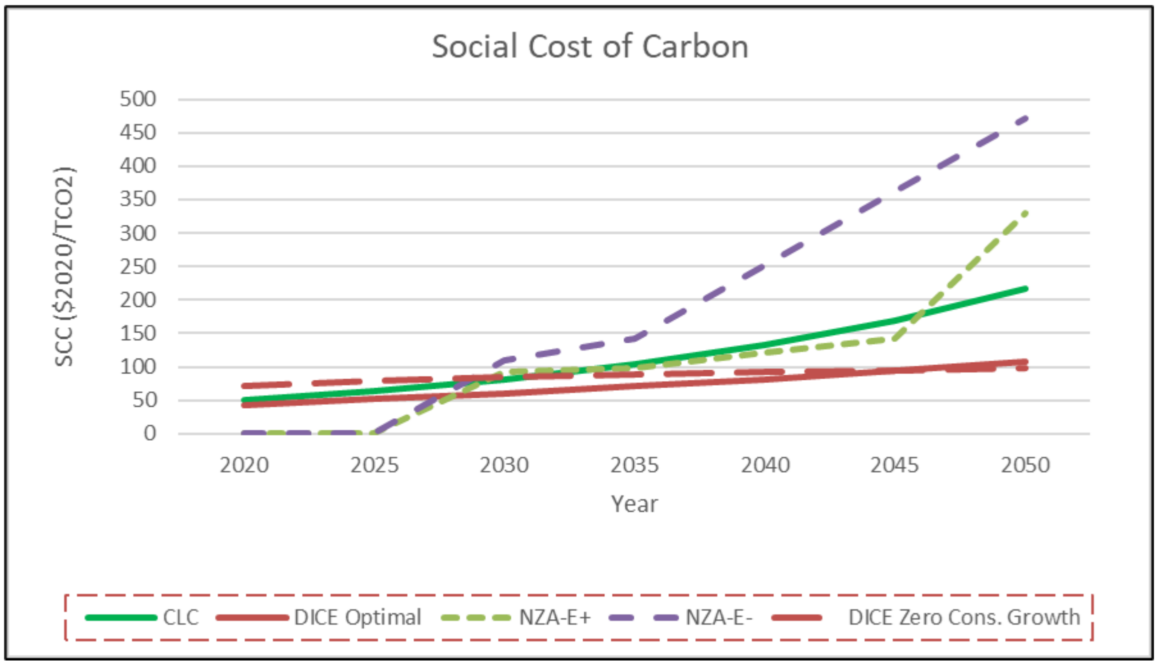
"Congress should consider an appropriate price on pollution from power production to level the playing field; create consistent market pull; and expand research, development, and commercialization of increasingly clean energy resources and technologies.

Correcting market prices will encourage more deployment of increasingly clean technologies. Where such technologies are already the lowest-price choice, they will become even more so; in other locations, a pollution price will make these technologies the most affordable option or narrow the gap. In addition to providing this market pull for the deployment of mature increasingly clean technologies, pollution pricing can be expected to spur the development of new, even more effective and competitively priced technologies."

This addresses the Research, Development, Demonstration and ***Deployment*** (RDD&D) market failure. Here the policy would recognize the need for the "appropriate price on pollution." What is the appropriate price on carbon emissions and why is this important?

The estimates for the Social Cost of Carbon from the DICE optimization, the CLC policy proposal, and the Net-Zero America cost effective trajectories diverge substantially.

The DICE model computes an optimal trajectory. The Clmate Leadership Council proposal includes a "Gradually Rising Carbon Fee … Carbon Dividends for All Americans … Significant Regulatory Simplification … Border Carbon Adjustment."[1] The Princeton Net-Zero America report sets a 2050 emissions target and estimates the implied marginal cost of emission reduction for a range of trajectories. (Larson et al., 2020, p. 204) The near term estimates are similar, but by 2050 the implied SCCs diverge from substantially from the DICE optimum. (Gollier, 2020) The "Zero Consumption" growth case shows slightly higher policy now, but little increase over time.



[1] https://clcouncil.org/our-plan/

The Social Cost of Carbon would define the "appropriate price on pollution." Too high or too low would reduce net welfare. Failure to price carbon leads to inefficient policies that impose costs but may have few benefits.

"Subsidies pose a more general problem in this context. They attempt to discourage carbon-intensive activities by making other activities more attractive. One difficulty with subsidies is identifying the eligible low-carbon activities. Why subsidize hybrid cars (which we do) and not biking (which we do not)? Is the answer to subsidize all low carbon activities? Of course, that is impossible because there are just too many low-carbon activities, and it would prove astronomically expensive. Another problem is that subsidies are so uneven in their impact. A recent study by the National Academy of Sciences looked at the impact of several subsidies on GHG emissions. It found a vast difference in their effectiveness in terms of CO_2 removed per dollar of subsidy. None of the subsidies were efficient; some were horribly inefficient; and others such as the ethanol subsidy were perverse and actually increased GHG emissions. The net effect of all the subsidies taken together was effectively zero!"

So in the end, it is much more effective to penalize carbon emissions than to subsidize everything else." (Nordhaus, 2013, p. 266)

"Mufson: ExxonMobil has been facing a revolt by shareholders unhappy with the company's financial performance and its approach to climate change. Is this part of a wave of efforts to push new and maybe difficult responsibilities onto corporations?

Nordhaus: It's just another example of efforts we're expending that are extremely costly and extremely divisive. It takes away valuable analyst time from other more fruitful activities such as pricing fossil fuels at the proper social costs. The movement to have companies measure and disclose their emissions is just an enormous waste of time. If you had a proper price on carbon, we wouldn't have to do that any more than we need companies to do an inventory of their wheat use or silicon use. It's another example of how we're going town a rabbit hole of measures. Even the central banks are getting involved."

(Steven Mufson Nordhaus Interview, Nobel winner's evolution from 'dark realist' to just plain realist on climate change, Washington Post, June 14, 2021.)

Subsidies are growing: RPS, RECs, PTCs, ITCs, DR, ZECs and zero emission targets.

“Subsidies are contagious. Competition in the markets could be replaced by competition to receive subsidies.” (Monitoring Analytics, 2017, p. 2)

“A typical finding is that using inefficient regulations or approaches will double the costs of meeting environment objectives.” (Nordhaus, 2013, p. 179)

On renewable portfolio standards (RPS): “…RPS policies’ statutory requirements for renewable generation frequently overstate their net impact on generation, because they often include generation that existed at the time of the policy’s passage… electricity prices increase substantially after RPS adoption… the estimates indicate that passage of RPS programs substantially reduces carbon emissions … putting together the findings on electricity prices and emissions implies that RPS programs achieve CO2 abatement at a relatively high cost. The cost to consumers per metric ton of CO2 ranges from $58 to $298 depending on specification and is above $100 in most specifications, suggesting that it is above conventional estimates of the social cost of carbon.” (Greenstone et al., 2020, pp. 2–3)

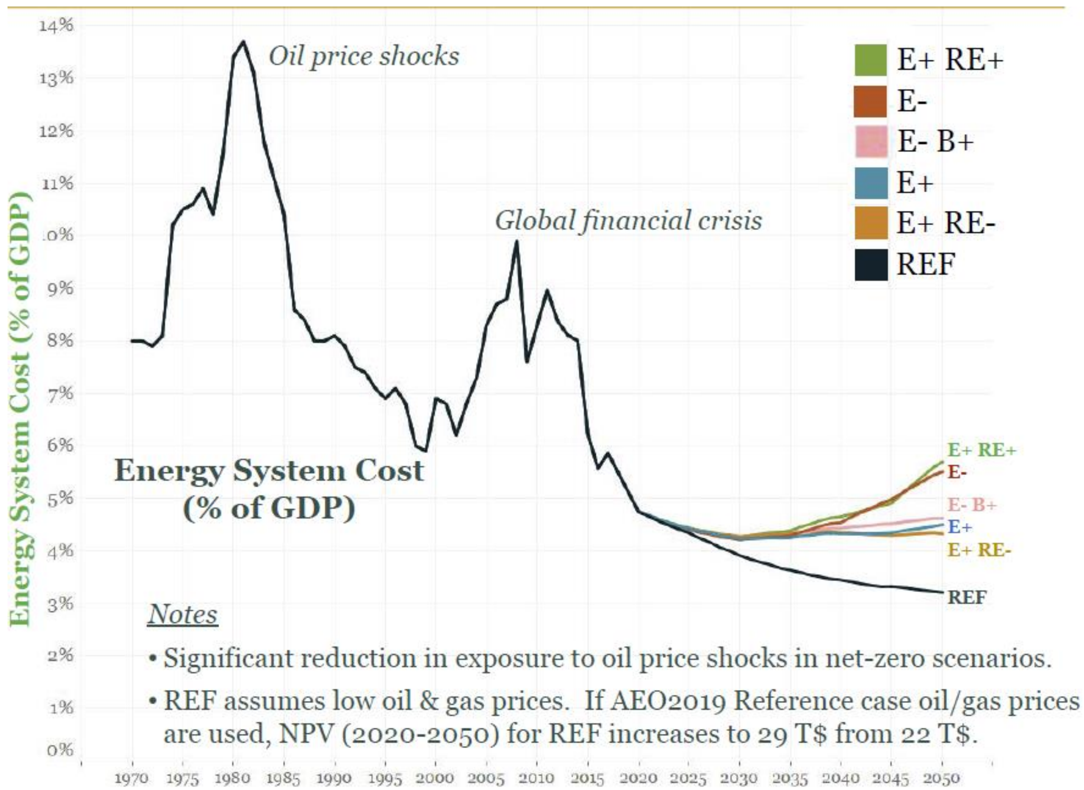
On Federal policies: ”…to calculate the carbon tax required to replace the major federal climate change policies that existed as of 2016: Corporate Average Fuel Economy (CAFE) Standards on light-, medium-, and heavy-duty vehicles; the Clean Power Plan (CPP); and the Renewable Fuel Standard (RFS). …the required carbon tax in 2020 is roughly $7 per tonne. In 2025, the required tax increases to roughly $22 per tonne; in 2030 the required tax is roughly $36 per tonne. These results underscore the economic power of a carbon tax, compared to the economically inefficient policies currently in place.” (Knittel, 2019, p. Abstract)

For examples from UK and Germany, see (Gugler et al., 2020).

The Princeton Net-Zero America Report covers the United States and compares a reference case with alternative scenarios for achieving net-zero emissions by 2050.

There is an encouraging message:

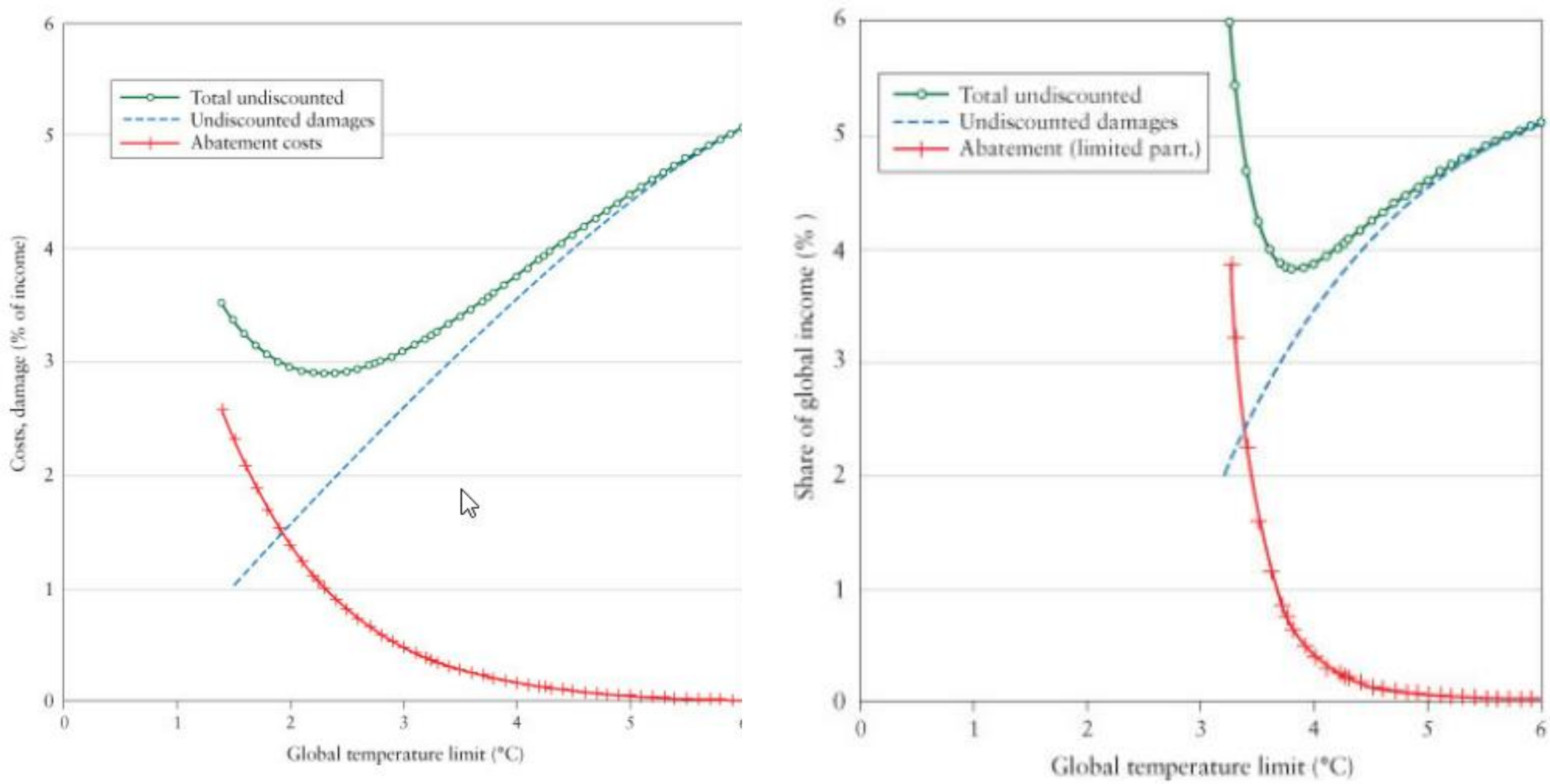
- The estimated costs are lower than in recent periods (Larson et al., 2020, p. 36).
- The policies are assumed to be efficiently implemented and involved broad participation.
- If it chooses, the United States could afford this policy.



But the same analysis raises questions:

- The costs of even efficient net zero policies are not trivial. Would all countries in the world also conclude that they were willing to pay the cost?
- How much would inefficient implementation and non-participation raise the cost and make the target unattainable?

Basic application of the DICE model assumes broad global participation. Trying to go beyond the point where marginal costs balance marginal benefits could materially affect participation, with stark implications for climate policy.



Total costs of different targets assuming limited full and 50% participation (Nordhaus, 2013, pp. 207, 209).

The DICE model and its applications by Nordhaus have long been a focal point of a subset of climate policy debates.

Could Nordhaus be right? Yes.

- We have delayed, and delayed, and the climate problem is growing.
- Governments are making aspirational promises that they should not, and won't, keep.
- We are doing the wrong things and increasing the costs of mitigation.
- The gaps between the rhetoric and the reality threaten a policy backlash that strikes at the heart of assumed universal participation. This will make everything harder.
- Carbon pricing that incorporates the Social Cost of Carbon is necessary, if we are serious. Critical supplements include innovation support through Research, Development and Demonstration phases (RD&D) with less focus on Deployment (the third "D").
- Adaptation is unavoidable. Research on and a policy for geoengineering are necessary, just in case it is needed.

Appendix Notes

Indifferent Transfers

Ignoring utility discounting, the equivalent tradeoff for consumption transfer between representative agents with different consumption levels with the DICE utility function satisfies

$$u'(c_1) = u'(c_2)\delta,$$

$$c_1^{-\alpha} = c_2^{-\alpha}\delta,$$

$$\delta = \left(\frac{c_2}{c_1}\right)^{\alpha}.$$

Hence, for the comparison in DICE, a reduction in 2020 consumption by one unit balanced by increase in 2100 consumption of

$$\delta = \left(\frac{c_{2100}}{c_{2020}}\right)^{1.45} = (4.41)^{1.45} = 8.59.$$

Deterministic Consumption

With deterministic consumption, the Epstein-Zin utility model reverts to the DICE formulation. For Epstein-Zin recursive preferences,

$$U_t = \left[(1-\beta)c_t^{1-\alpha} + \beta\left(E_t\left[U_{t+1}^{1-\theta}\right]\right)^{1-\alpha/1-\theta}\right]^{1/1-\alpha}.$$

With no uncertainty, this becomes as in

$$U_t^{1-\alpha} = (1-\beta)c_t^{1-\alpha} + \beta\left(U_{t+1}^{1-\alpha}\right).$$

Use the ordinally equivalent transformation (Kasa, 2018),

$$V = \frac{1}{1-\alpha} U^{1-\alpha}.$$

We obtain the time additive preferences, as in DICE.

$$V_t = (1-\beta)\frac{c_t^{1-\alpha}}{1-\alpha} + \beta(V_{t+1}) = \frac{(1-\beta)}{\beta}\left[\sum_{t=1}\beta^t \frac{c_t^{1-\alpha}}{1-\alpha}\right].$$

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