$50

~$50 Social Cost of CO_2

Based on 3% constant discount rate, and an average of 3 climate-economy models, including DICE

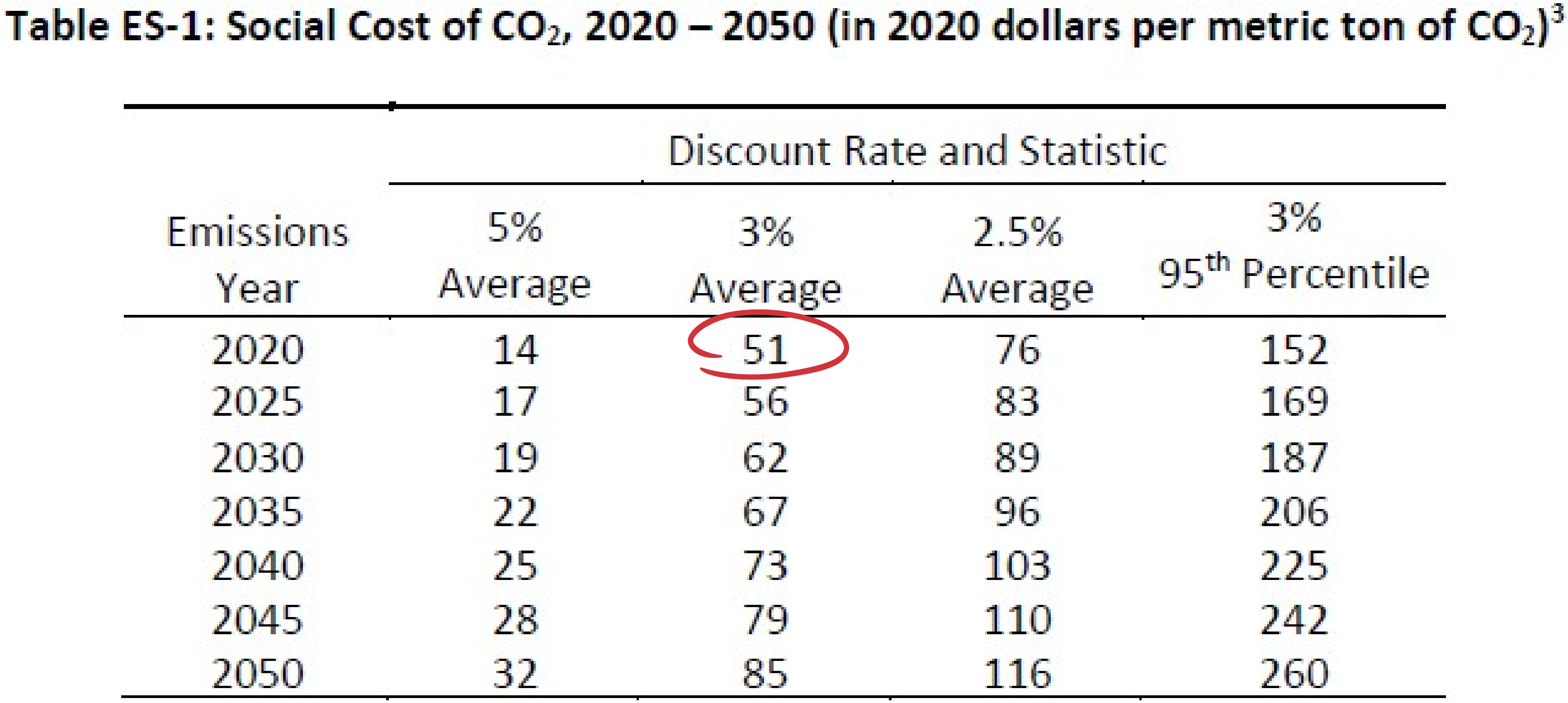

Table ES-1: Social Cost of CO_2, 2020 – 2050 (in 2020 dollars per metric ton of CO_2)[3]

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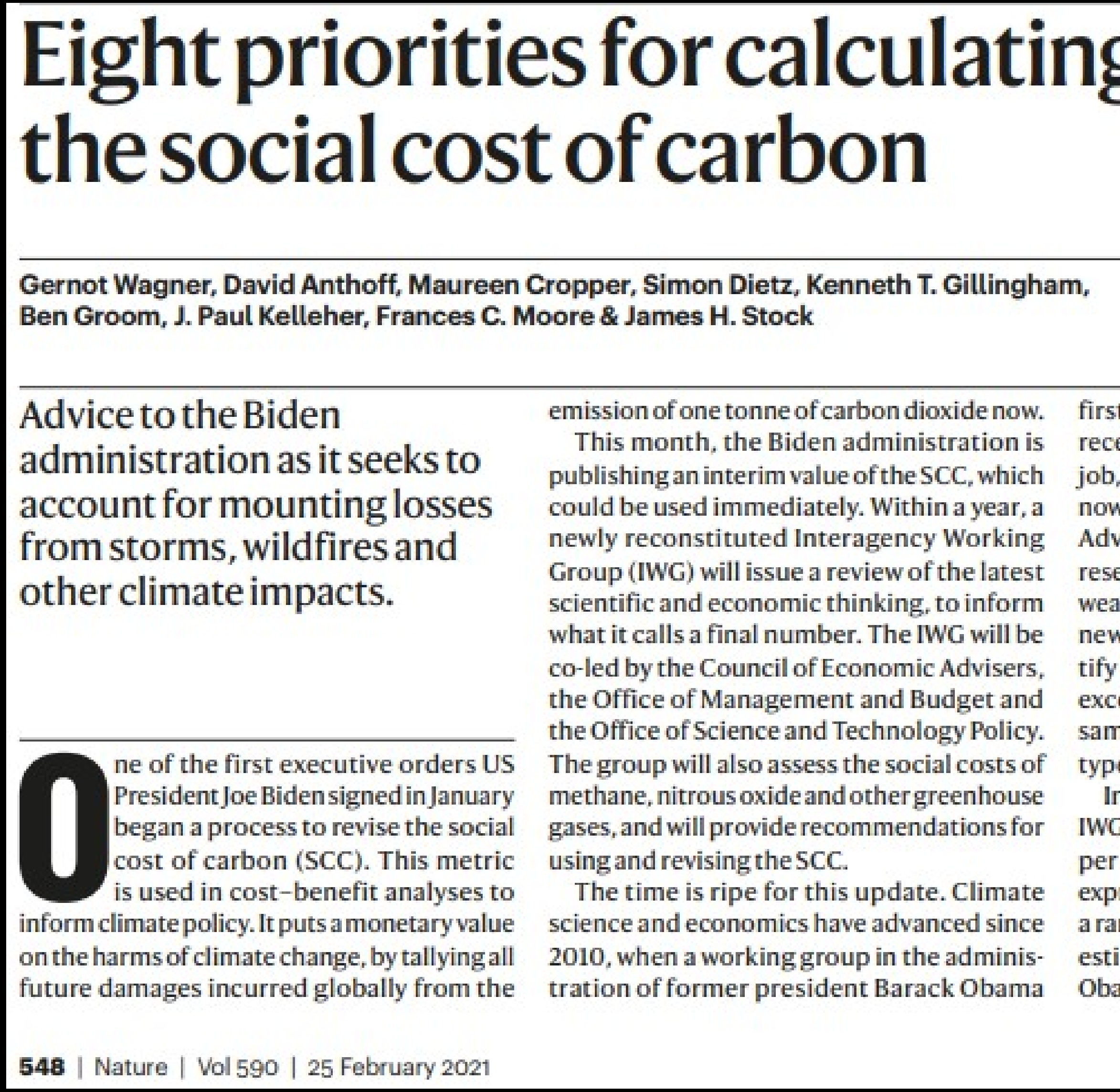
2035	22	67	96	206
2040	25	73	103	225
2045	28	79	110	242
2050	32	85	116	260

~$50 'interim' Biden SC-$CO_2$,
up from $1-7 Trump figure

Source: "Technical Support Document: Social Cost of Carbon, Methane, and Nitrous Oxide Interim Estimates under Executive Order 13990" (February 2021).



Eight priorities for calculating the social cost of carbon

Gernot Wagner, David Anthoff, Maureen Cropper, Simon Dietz, Kenneth T. Gillingham, Ben Groom, J. Paul Kelleher, Frances C. Moore & James H. Stock

Advice to the Biden administration as it seeks to account for mounting losses from storms, wildfires and other climate impacts.

One of the first executive orders US President Joe Biden signed in January began a process to revise the social cost of carbon (SCC). This metric is used in cost–benefit analyses to inform climate policy. It puts a monetary value on the harms of climate change, by tallying all future damages incurred globally from the emission of one tonne of carbon dioxide now.

This month, the Biden administration is publishing an interim value of the SCC, which could be used immediately. Within a year, a newly reconstituted Interagency Working Group (IWG) will issue a review of the latest scientific and economic thinking, to inform what it calls a final number. The IWG will be co-led by the Council of Economic Advisers, the Office of Management and Budget and the Office of Science and Technology Policy. The group will also assess the social costs of methane, nitrous oxide and other greenhouse gases, and will provide recommendations for using and revising the SCC.

The time is ripe for this update. Climate science and economics have advanced since 2010, when a working group in the administration of former president Barack Obama first calculated the n
recent update in 20
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Advances in attri
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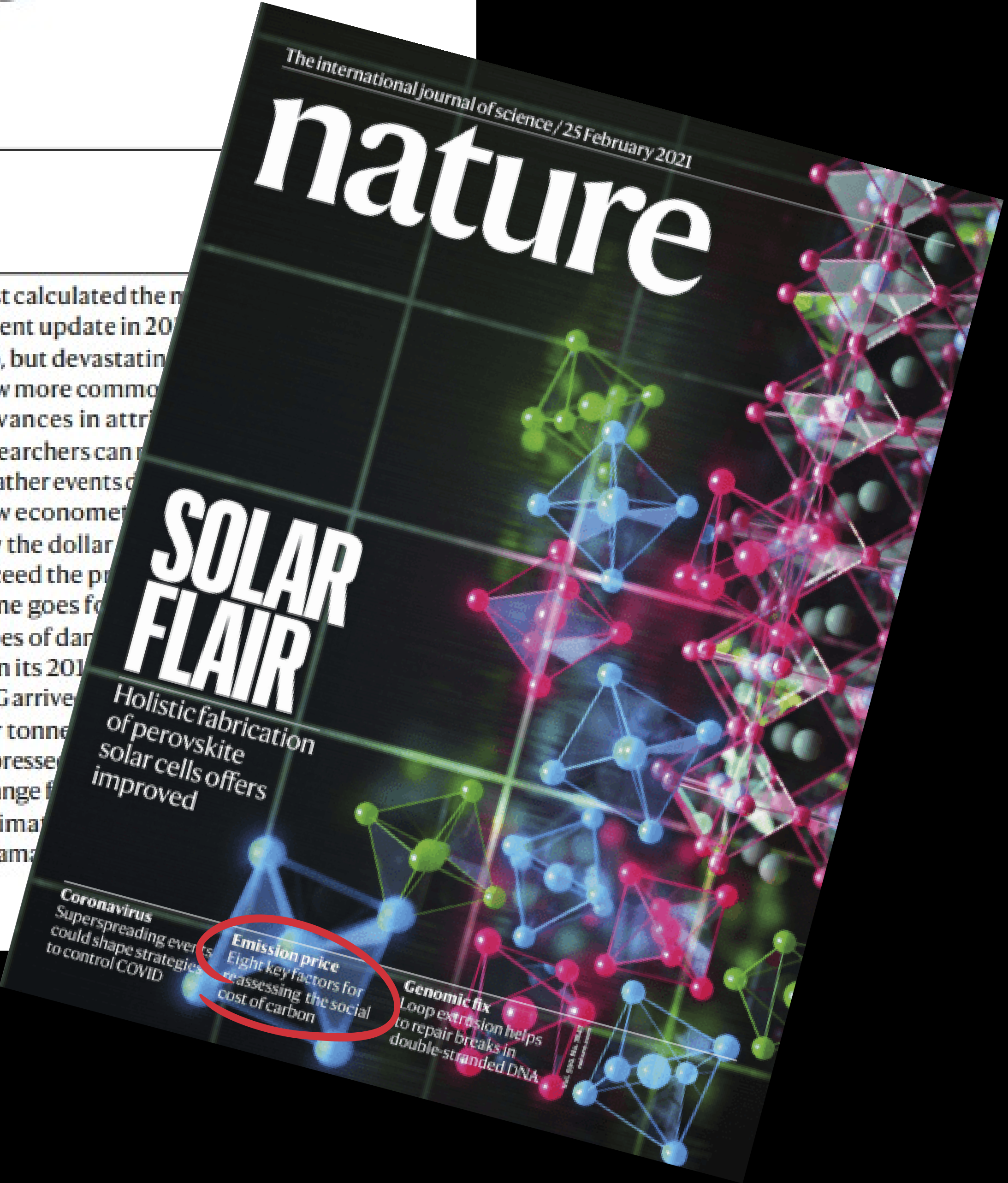
548 | Nature | Vol 590 | 25 February 2021



The international journal of science / 25 February 2021

nature

SOLAR FLAIR

Holistic fabrication of perovskite solar cells offers improved

Coronavirus Superspreading events could shape strategies to control COVID

Emission price Eight key factors for reassessing the social cost of carbon

Genomic fix Loop extrusion helps to repair breaks in double-stranded DNA

gwagner.com/SCC-8

>$100

>$100:

Climate damage quantification

including tipping points

Tail risks

Discounting

Risk calibration, equity, etc.

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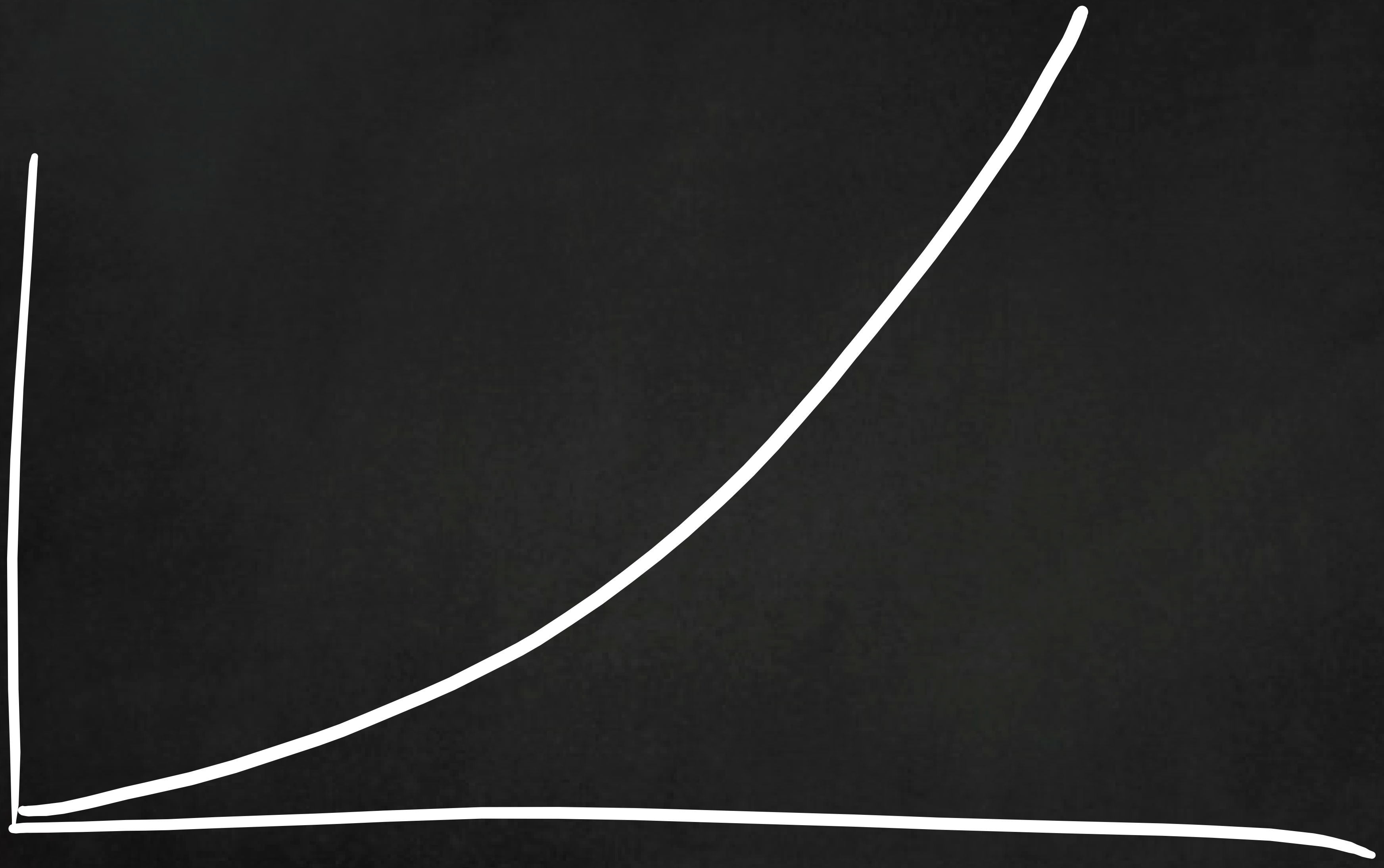
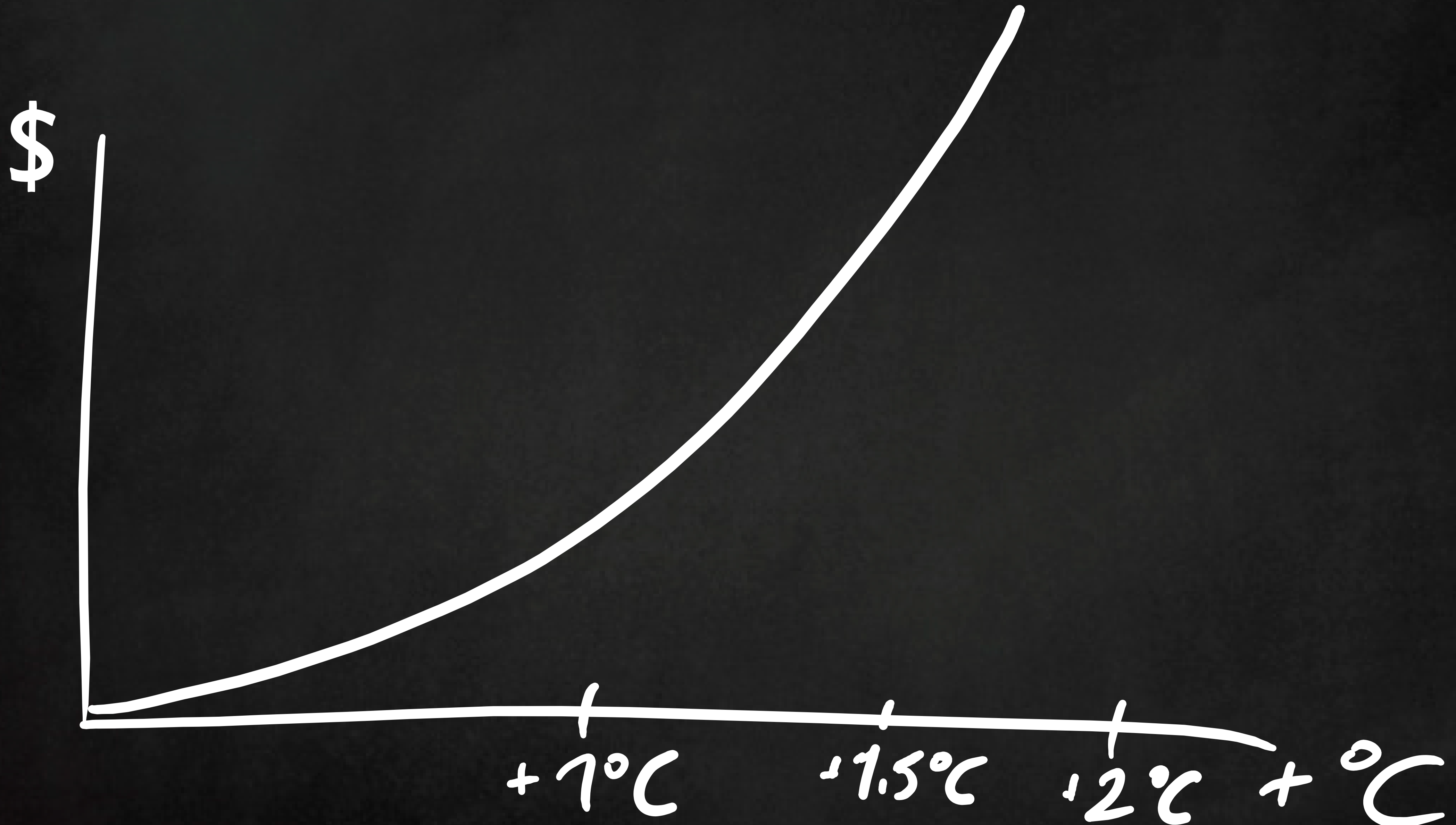
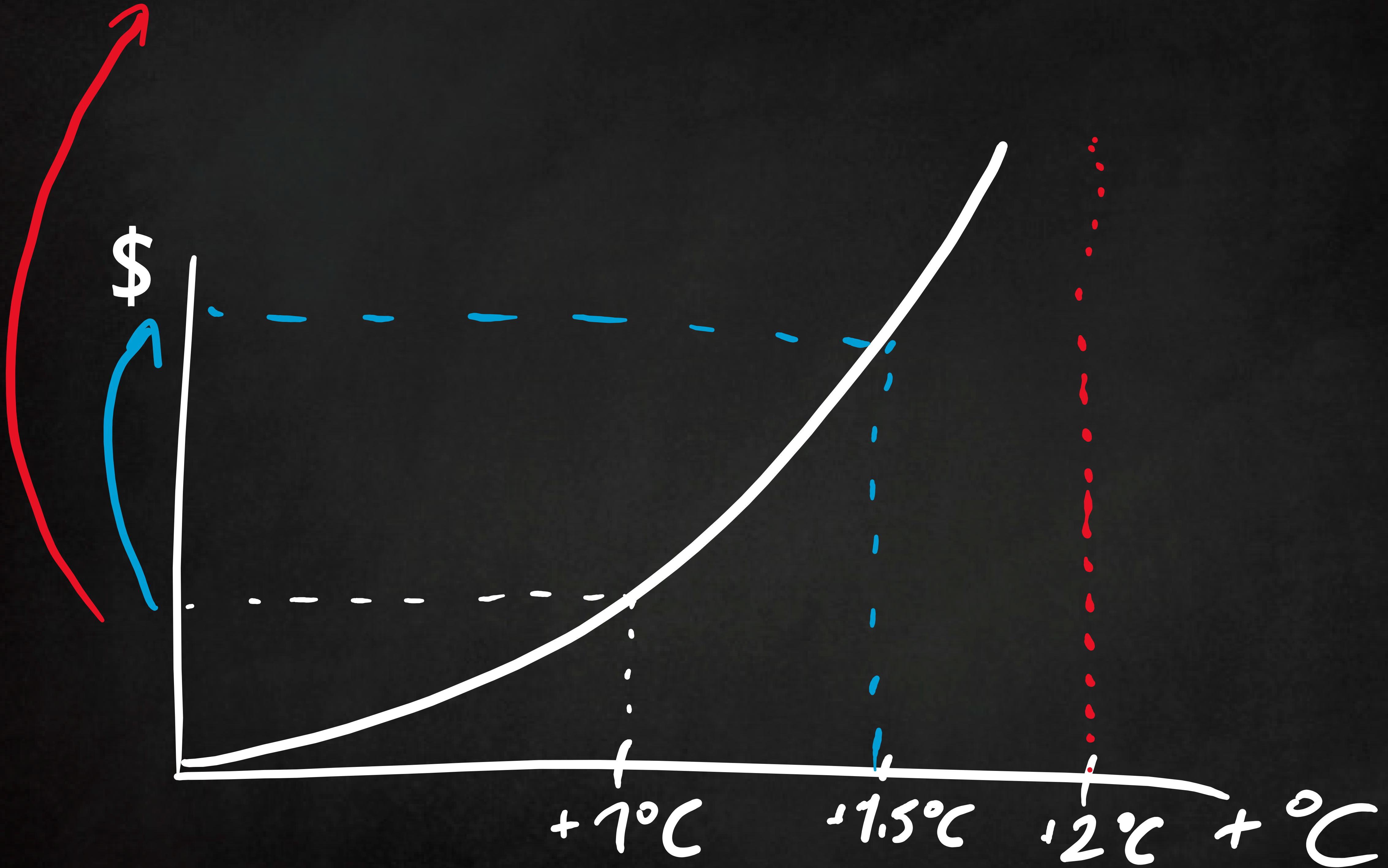



$
+1°C
+1,5°C
+2°C
+ °C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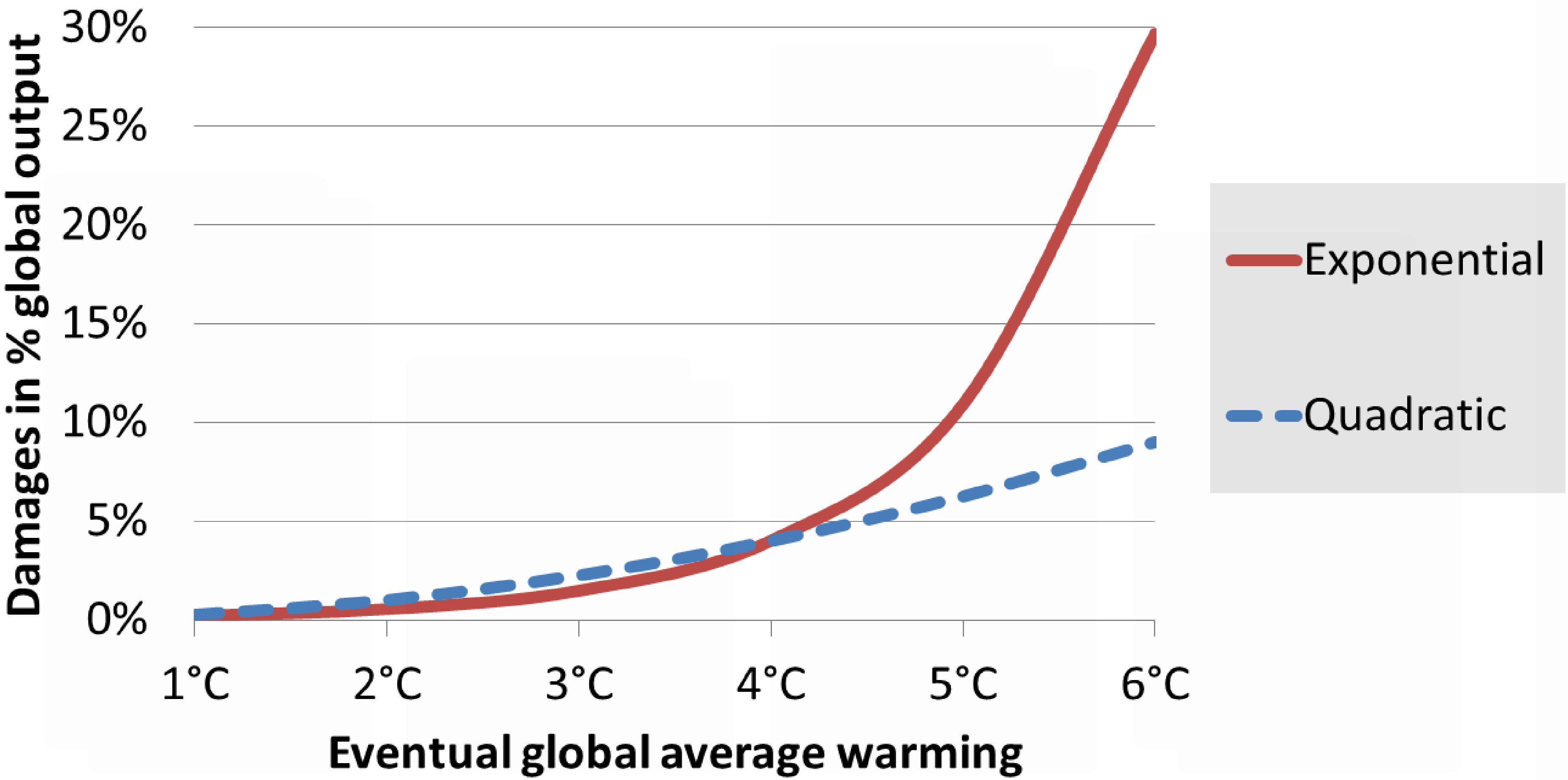
Choice of damage function critical

Integrated Assessment Models beginning with Nordhaus (1992) have assumed quadratic damage extrapolations



Exponential not any more “correct”; point is we don’t—can’t(?)—know.

Source: Wagner & Weitzman ‘s *Climate Shock* (2015)

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Climate damage quantification

including tipping points

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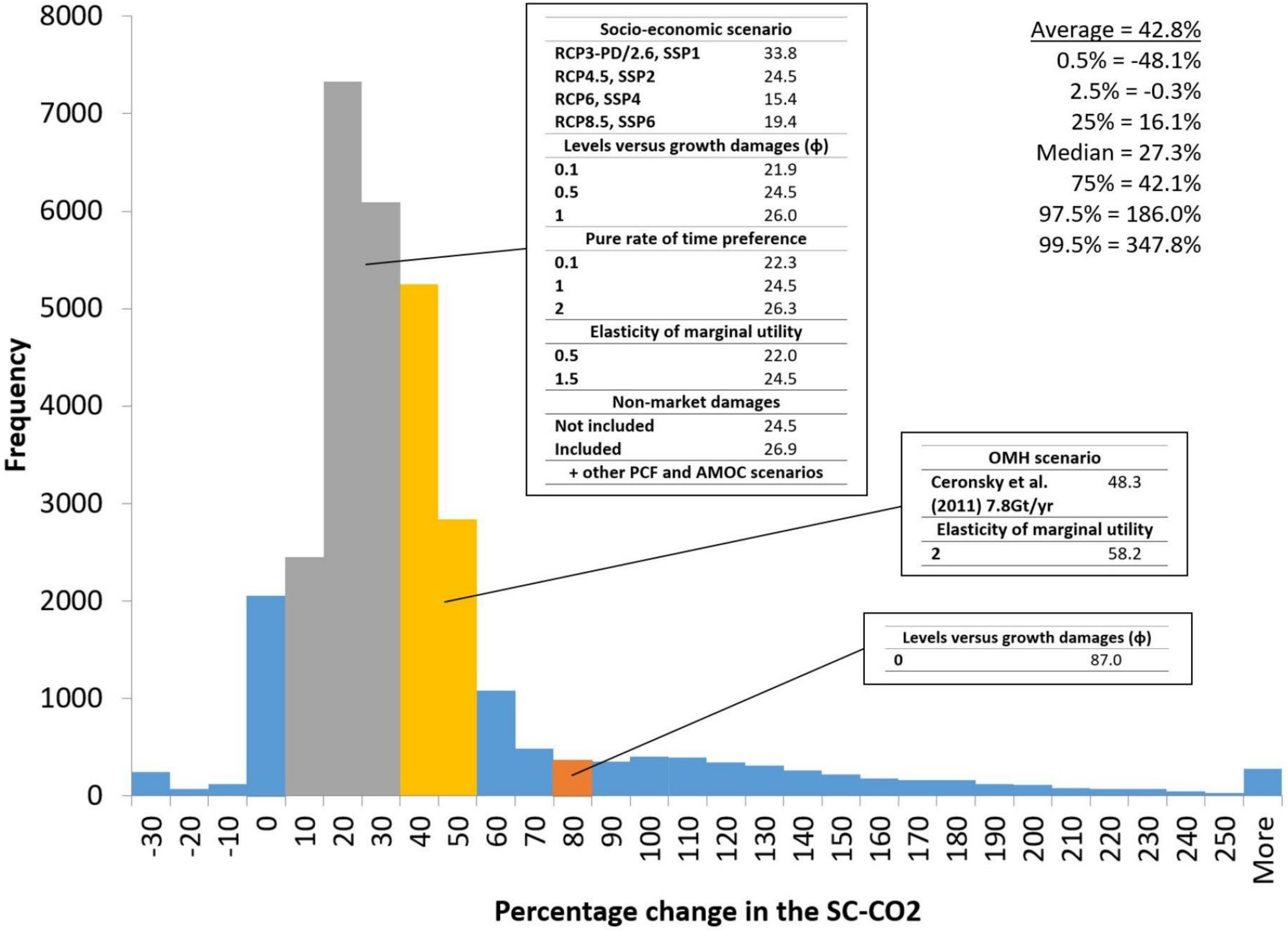
Economic impacts of tipping points in the climate system

Tipping points increase SCC by between ~27-43%, with large, right-skewed distribution



Socio-economic scenario	
RCP3-PD/2.6, SSP1	33.8
RCP4.5, SSP2	24.5
RCP6, SSP4	15.4
RCP8.5, SSP6	19.4
Levels versus growth damages (ϕ)	
0.1	21.9
0.5	24.5
1	26.0
Pure rate of time preference	
0.1	22.3
1	24.5
2	26.3
Elasticity of marginal utility	
0.5	22.0
1.5	24.5
Non-market damages	
Not included	24.5
Included	26.9
+ other PCF and AMOC scenarios	

OMH scenario	
Ceronsky et al. (2011) 7.8Gt/yr	48.3
Elasticity of marginal utility	
2	58.2

Levels versus growth damages (ϕ)	
0	87.0

Average = 42.8%
0.5% = -48.1%
2.5% = -0.3%
25% = 16.1%
Median = 27.3%
75% = 42.1%
97.5% = 186.0%
99.5% = 347.8%

Source: Dietz, Rising, Stoerk & Wagner (*PNAS* 2021), gwagner.com/tipping-economics

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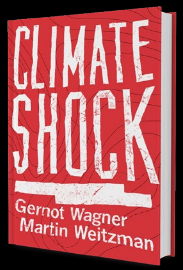

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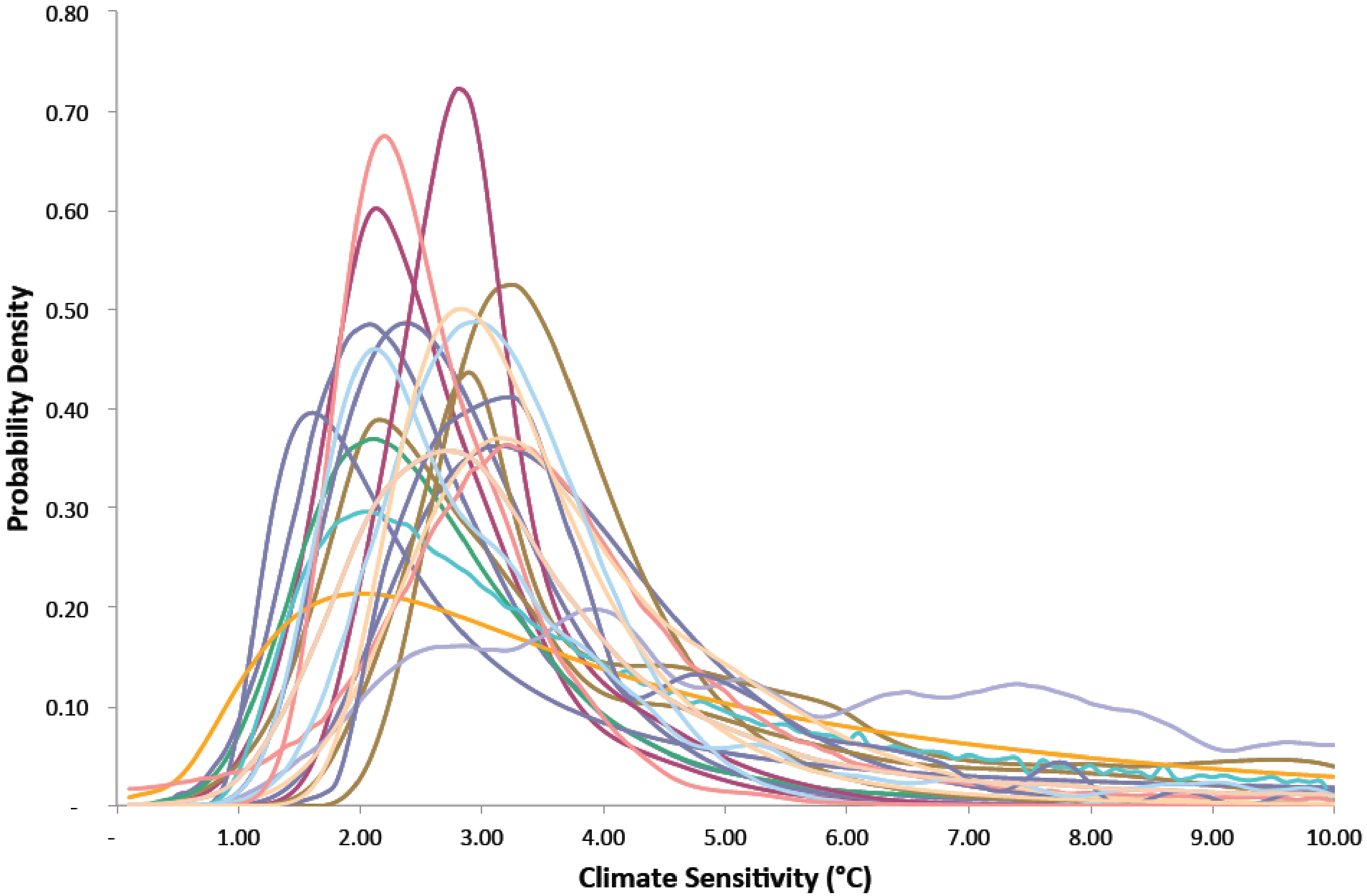
Climate sensitivity with long right tail

Long history of calculations, going back to Svante Arrhenius (1896)

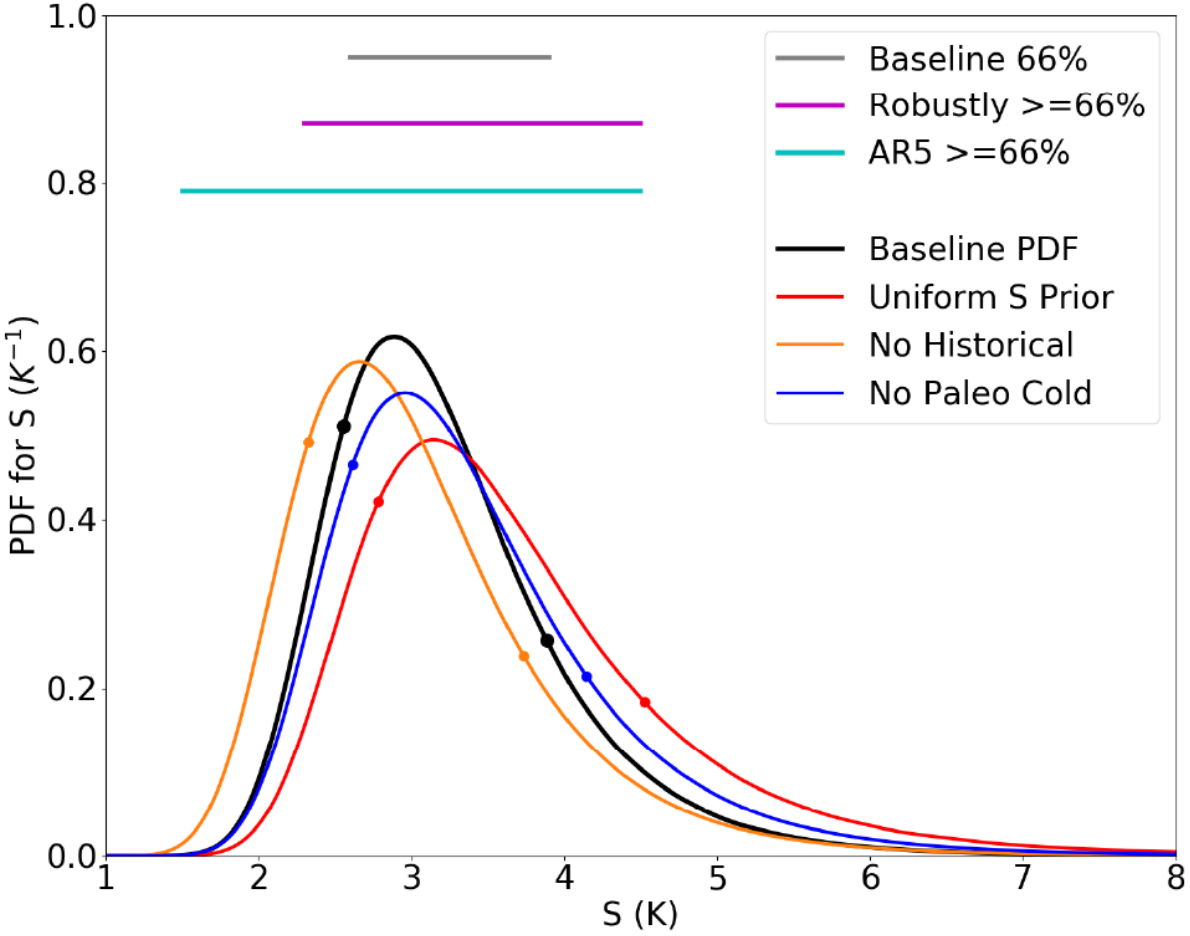


Answer to the question
what happens to °C as CO_2 doubles

Source: Meinshausen *et al* (2009)

Climate sensitivity “likely” between ~2-4.5°C

Latest assessment narrows 66% “likely” range from 1.5-4.5°C



Tail risk might dwarf importance of “likely” range

Source: Sherwood et al (2020)

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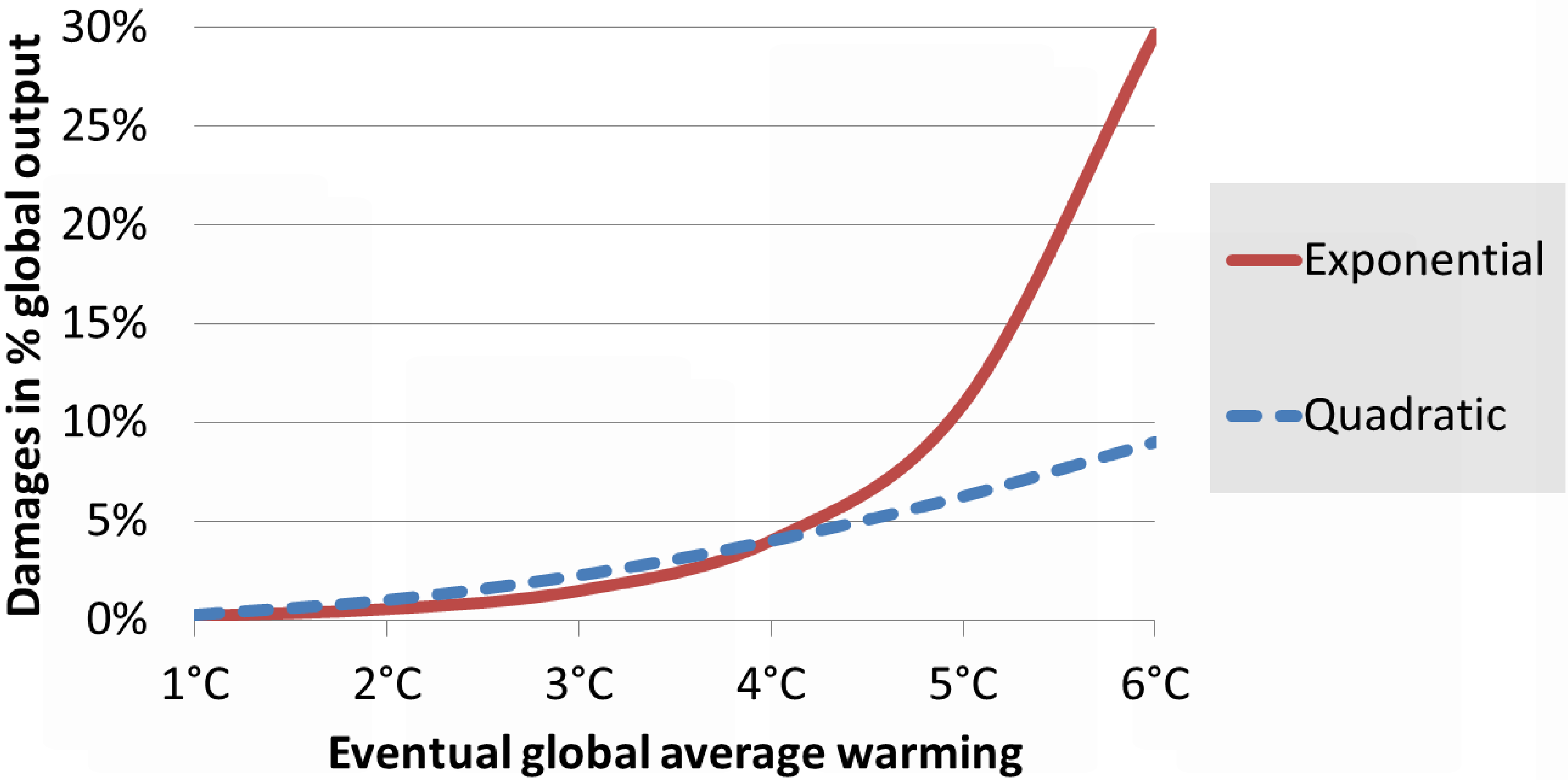
Integrated Assessment Models beginning with Nordhaus (1992) have assumed quadratic damage extrapolations



Exponential not any more "correct"; point is we don't—can't(?)—know.

Source: Wagner & Weitzman 's *Climate Shock* (2015)

It’s not over ‘til the fat tail zings

Rapidly increasing probability of extreme final temperatures

By 2100, per IEA’s
“New Policies Scenario”

CO_2e (ppm)	400	450	500	550	600	650	700	750	800
Median Δ°C	1.3°C	1.8°C	2.2°C	2.5°C	2.7°C	3.2°C	3.4°C	3.7°C	3.9°C
Prob >6°C	0.04%	0.3%	1.2%	3%	5%	8%	11%	14%	17%

<1.5x

10x

2°C is bad enough, what about 6°C?

Source: Wagner & Weitzman’s *Climate Shock* (2015)

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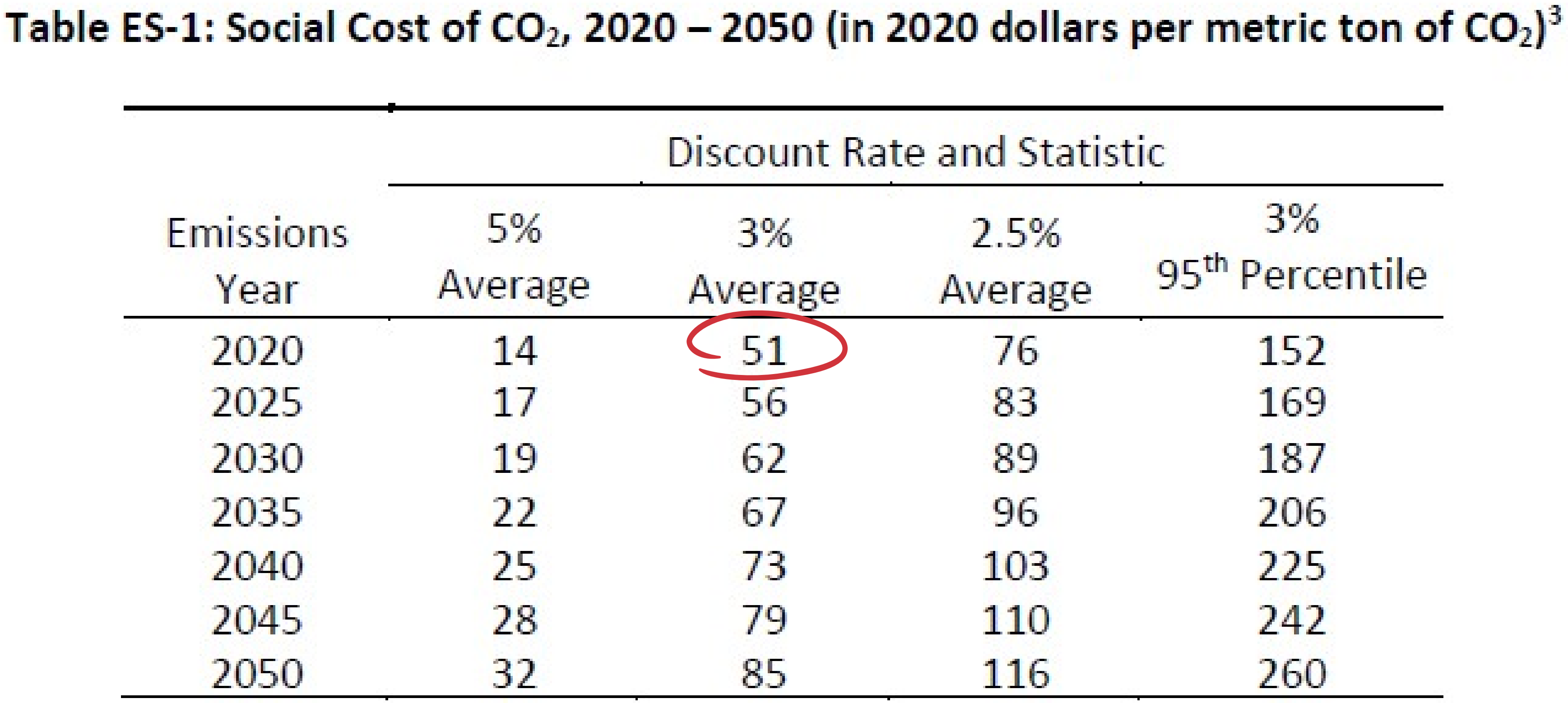
~$50 Social Cost of CO_2

Based on 3% constant discount rate, and an average of 3 climate-economy models, including DICE



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2050	32	85	116	260

New York's "central" SCC is $125, using 2% instead of 3%

Source: "Technical Support Document: Social Cost of Carbon, Methane, and Nitrous Oxide Interim Estimates under Executive Order 13990" (February 2021).

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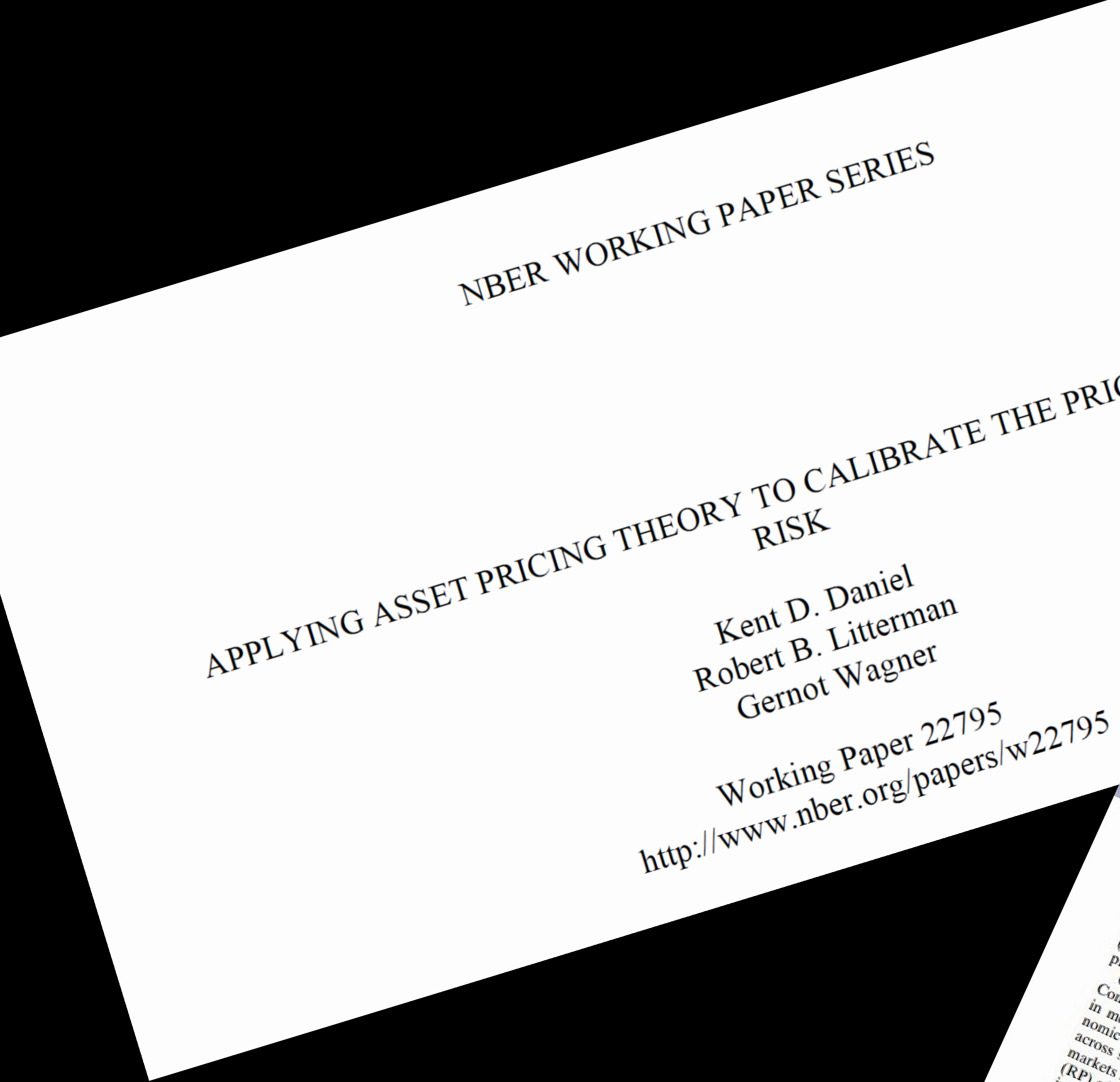

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RISK

Kent D. Daniel
Robert B. Litterman
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Working Paper 22795
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Declining CO_2 price paths

Kent D. Daniel[a,b,1], Robert B. Litterman[c,1], and Gernot Wagner[d,1,2,3]

[a]Columbia Business School, New York, NY 10027; [b]National Bureau of Economic Research, Cambridge, MA 02138; [c]Kepos Capital, New York, NY 10018; and [d]Harvard University Center for the Environment, Cambridge, MA 02138

Edited by Jose A. Scheinkman, Columbia University, New York, NY, and approved September 9, 2019 (received for review October 9, 2018)

Pricing greenhouse-gas (GHG) emissions involves making trade-offs between consumption today and unknown damages in the (distant) future. While decision making under risk and uncertainty is the forte of financial economics, important insights from pricing financial assets do not typically inform standard climate–economy models. Here, we introduce EZ-Climate, a simple recursive dynamic asset pricing model that allows for a calibration of the carbon dioxide (CO_2) price path based on probabilistic assumptions around climate damages. Atmospheric CO_2 is the "asset" with a negative expected return. The economic model focuses on society's willingness to substitute consumption across time and across uncertain states of nature, enabled by an Epstein–Zin (EZ) specification that delinks preferences over risk from intertemporal substitution. In contrast to most modeled CO_2 price paths, EZ-Climate suggests a high price today that is expected to decline over time as the "insurance" value of mitigation declines and technological change makes emissions cuts cheaper. Second, higher risk aversion increases both the CO_2 price and the risk premium relative to expected damages. Lastly, our model suggests large costs associated with delays in pricing CO_2 emissions. In our base case, delaying implementation by 1 y leads to annual consumption losses of over 2%, a cost that roughly increases with the square of time per additional year of delay. The model also makes clear how sensitive results are to key inputs.

climate risk | asset pricing | cost of carbon

For over 25 y, the dynamic integrated climate–economy (DICE) model (1–3) has been the standard tool for analyzing CO_2 emissions-reductions pathways, and for good reason. One attraction is its simplicity, turning a "market failure on the greatest scale the world has seen" (4) and "the mother of all externalities" (5) into a model involving fewer than 20 main equations, 3 representing the climate system (6). DICE has spawned many variants (7). It has also helped set the tone for what many consider "optimal" CO_2 price paths. The core trade-off between economic consumption and climate damages leads to relatively low CO_2 prices today rising over time.

DICE and models like it have well-known limitations, including how they represent climate risk and uncertainty (7–15). DICE, for example, is not an optimal-control model, as commonly understood by economists employing modern dynamic economic analysis, even though it lends itself to those extensions (9–12). The underlying structure all but prescribes a rising CO_2 price path over time.

One important limitation is the form of the utility function. Constant relative risk aversion (CRRA) preferences, standard in most climate–economy models (1, 7, 16), assume that economic agents have an equal aversion to variation in consumption across states of nature and over time. Evidence from financial markets suggests that this is not the case (17). The risk premium (RP) of equities over bonds points to a fundamental difference in how much society is willing to pay to substitute consumption risk across states of nature compared to over time (18, 19). Some have explained the discrepancy by allowing for extreme events (20–22), and others have looked to more flexible preferences (23–26) or both (27). Our own preference specification
Epstein and Zin (EZ) (24, 25).

EZ Preferences

Here, we use EZ preferences and focus on climate uncertainties. We approach climate change as an asset pricing problem with atmospheric CO_2 as the "asset." The value of an investment in reducing CO_2 emissions depends on the state of nature, represented by its fragility θ_t. That, in turn, helps determine the discount rate applied to the damages that would have occurred without the investment.

Our representative agent maximizes a recursive utility U_t based on consumption c_t and expectations E_t over future utility for times $t \in \{0, 1, 2, \ldots, T-1\}$:

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

Parameters α and ρ measure the agent's willingness to substitute consumption across states of nature and across time, respectively. (See *Methods* for the final-period utility U_T and further derivations.) CRRA preferences are a special case, with $\alpha = \rho$. Unlike with CRRA, Eq. **1** implies that CO_2 prices no longer collapse to zero with increasing risk aversion (RA) and equity risk premia (Fig. 1*A*). The same goes for the portion of CO_2 prices explained by RA (Fig. 1*B*).

EZ preferences have since found their way into the climate–economic literature (9–12, 28–35). Some have embedded EZ into DICE (28, 35), and others employ supercomputers to solve (9–12). The complexity typically does not allow for analytic solutions (34). We here follow a simple binomial-tree model with a long history in financial modeling application (36). It is precisely this modeling choice—standard in financial economics but novel to climate–economic applications—that leads to our fundamentally differing CO_2 price paths. Mitigating climate risk provides

Significance

Risk and uncertainty are important in pricing climate damages. Despite a burgeoning literature, attempts to marry insights from asset pricing with climate economics have largely failed to supplement—let alone supplant—decades-old climate–economy models, largely due to their analytic and computational complexity. Here, we introduce a simple, modular framework that identifies core trade-offs, highlights the sensitivity of results to key inputs, and helps pinpoint areas for further work.

Author contributions: K.D.D., R.B.L., and G.W. designed research, performed
contributed new analytic tools, and wrote the paper.

The authors declare no competing interest.

This article is a PNAS Direct Submission.

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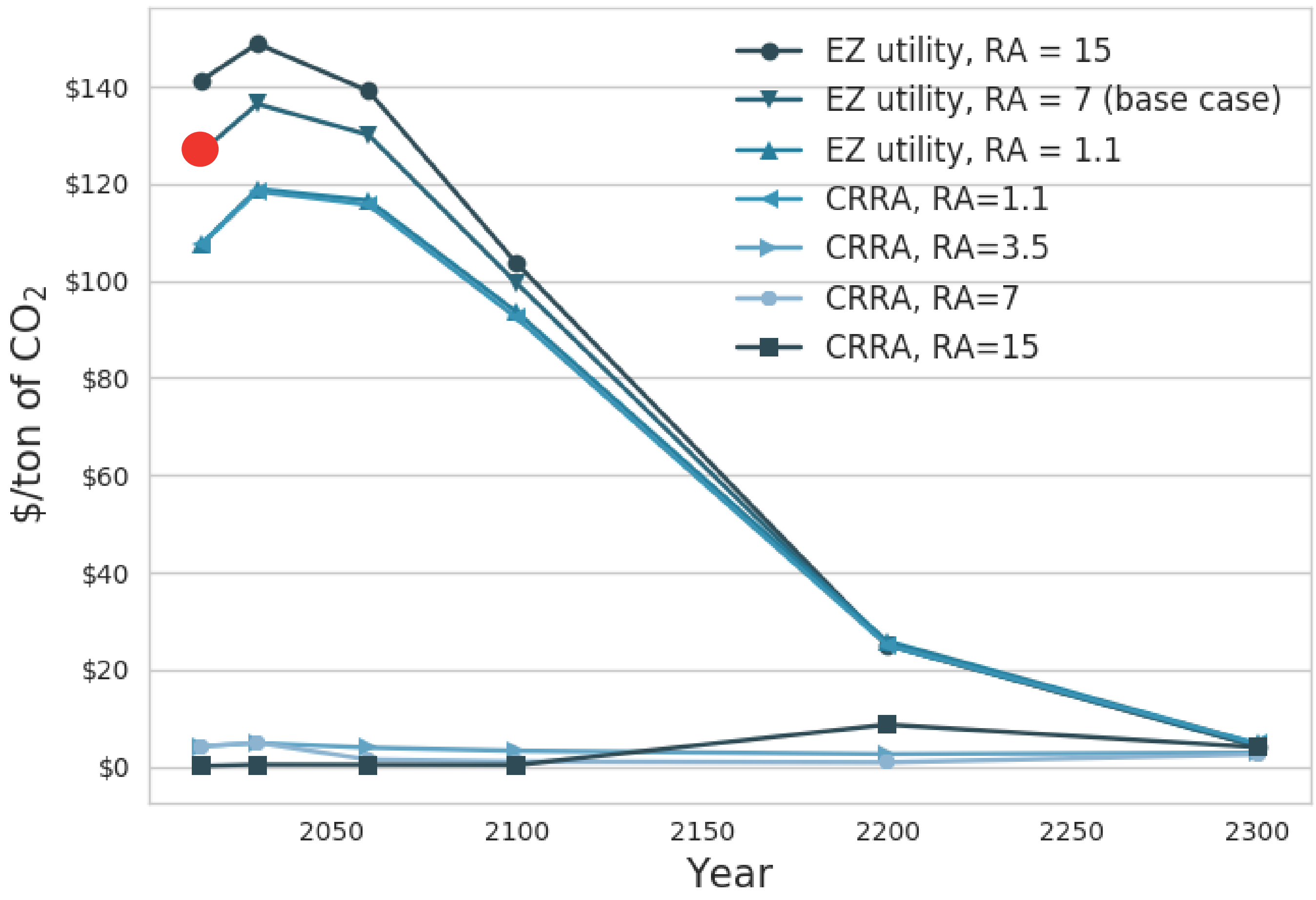
High ‘optimal’ CO_2 price today, declining over time?

No difference between CRRA and EZ utility at RA=1.1, large differences for RA>~3



Source: Daniel, Litterman & Wagner (*PNAS*2019), gwagner.com/ezclimate

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