CLIMATE SHOCK

THE ECONOMIC CONSEQUENCES OF A HOTTER PLANET

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Notes

PREFACE: POP QUIZ

Page ix—**Two quick questions**: Princeton's Robert Socolow has started many a presentation with a version of this quiz, asking audiences whether they consider climate change "an urgent matter" and fossil fuels "hard to displace." He groups the resulting views into four broad buckets, reproduced here with permission, and with slight modifications:

		Is getting the world off fossil fuels difficult?	
		No	Yes
Is climate change an urgent problem?	No	A low-carbon world unmotivated by climate considerations.	Perhaps most of the general public, and parts of the energy industry.
	Yes	Many environmentalists, including nuclear advocates.	Our working assumption.

Socolow, "Truths," searches for solutions firmly grounded in this "working assumption." Oliver Morton, editor at the *Economist*, introduced an August 2013 debate on geoengineering at the Massachusetts Institute of Technology with these two questions. Morton echoed Socolow's conclusion that, to avoid cognitive dissonance, most people answer "Yes" to either one or the other question, but not both. In the packed lecture hall that evening at MIT, most answered "Yes" to both, a clear indication of the type of people currently attracted to geoengineering conversations.

Page x—**Standard economic treatments**: For a popular, standard perspective on the science and economics of climate change, see Nordhaus, *Climate Casino*. For more, see the "DICE" entry on page 36 in chapter 2.

CHAPTER 1. 911

Page 1—**exploded in the sky**: See Artemieva, "Solar System: Russian Skyfall."

Page 1—**$2 or 3 billion**: Section 321 of the NASA Authorization Act of 2005 directs NASA both to "detect, track, catalog and characterize certain near-earth asteroids and comets" and to write a report including "analysis of possible alternatives that NASA could employ to divert an object on a likely collision course with Earth." The options range from "non-nuclear kinetic impactors," described as the most mature technology, to a "nuclear standoff explosion," possibly the most effective ("Near-Earth Object Survey"). See "Defending Planet Earth" about the inadequacy of current funding. The report concludes that $250 million per year for ten years would allow NASA to launch an actual test of deflecting an asteroid.

The United Nations recognizes asteroid deflection as a global issue and recently voted to create the "International Asteroid Warning Group," where members will share information about potentially dangerous approaching asteroids, and work with the UN Committee on the Peaceful Uses of Outer Space to launch a defense. The UN began discussing the creation of such an international warning group after a meteor exploded over Russia in February 2013, without the world's space agencies knowing beforehand ("Threat of Space Objects Demands International Coordination, UN Team Says").

Page 1—**1-in-1,000-year event**: An asteroid impact of the size that may warrant a full-on defense may be a one-in-1,000-year event. The probability of an asteroid impact the size of the one that exploded above Chelyabinsk Oblastin February 2013 is commonly seen to be around one in 100 years (Artemieva, "Solar System: Russian Skyfall"). However, the latest research puts the probability of a Chelyabinsk-sized asteroid at ten times that estimate (Brown et al., "500-Kiloton Airburst").

Page 2—**major extinction event**: Kolbert, *Sixth Extinction*, looks at prior extinction events and then mainly focuses on the current, human-caused one. For a summary of Kolbert's arguments, see: Dreifus, "Chasing the Biggest Story on Earth."

Page 2—**past 65 million years**: Diffenbaugh and Field, "Changes in Ecologically Critical Terrestrial Climate Conditions." This even includes the Palaeocene–Eocene Thermal Maximum (PETM) around 56 million years ago, when the globe warmed by at least 5°C (9°F) in less than 10,000 years, a rate of change still ten times slower than the projected rate of global average surface temperature increase in the IPCC's RCP2.6 scenario.

Page 2—**100-year flood**: Lovett, "Gov. Cuomo."

Page 2—**Irene killed 49**: Avila and Cangialosi, *Tropical Cyclone Report*. "Irene by the Numbers" estimates that 2.3 million people were under evacuation orders in the United States.

Page 2—**Sandy killed 147**: Blake et al., Tropical Cyclone Report.

Page 2—**Typhoon Haiyan**: As of January 28, 2014, Haiyan was estimated to have displaced 4.1 million, and killed over 6,000 people ("Philippines: Typhoon Haiyan Situation Report No. 34"). In the Philippines, Haiyan was named "Typhoon Yolanda."

Any of these figures are likely significant underestimates, as they exclude estimates of the negative impact storms have on a family's ability to properly care for themselves and their children. Antilla-Hughes and Hsiang, "Destruction, Disinvestment, and Death," shows that "unearned income and excess infant mortality in the year after typhoon exposure outnumber immediate damages and death tolls roughly 15-to-1."

Page 2—**Typhoon Bopha**: According to "Report: The After Action Review / Lessons Learned Workshops for Typhoon Bopha Response," Typhoon Bopha affected 6.2 million people, destroyed 230,000 homes, and killed 1,146 people, with another 834 still missing. The latest situation report published on the effects of Bopha counts over 700,000 who have sought shelter in evacuation centers plus 1.06 million outside evacuation centers during the peak of displacement, for a total of 1.76 million displaced (National Disaster Risk Reduction and Management Council), rounded to 1.8 million in the text. Also see Antilla-Hughes and Hsiang, "Destruction, Disinvestment, and Death," for why these numbers are likely significant underestimates of full costs and deaths.

Page 3—**European summer heat wave**: Robine et al., "Death Toll."

Page 3—**equipped to cope**: Deschênes and Moretti, "Extreme Weather Events," estimate that Americans' mobility from the Northeast to the warmer Southwest climate has significantly increased average life expectancy since 1980. Barreca et al., "Adapting to Climate Change," highlights the importance of residential air-conditioning in the drastically declining temperature-mortality relationship in the United States.

Page 3—**waters off the coast**: Tollefson, "Hurricane Sandy," discusses the link between climate change and hurricanes. It also notes that "the expected increase due to global warming is just 0.6°C," concluding that "while the changing climate certainly plays a part . . . there is plenty of space for natural variability." Pun, Lin, and Lo, "Tropical Cyclone Heat Potential," discusses the recent warming trends in the water east of the Philippines, which most likely contributed to the severity of Typhoon Haiyan. Normile, "Supertyphoon's Ferocity," draws this link.

By comparison, global average sea surface warming has been around 0.1°C (0.2°F) per decade in the past four decades (Summary for Policymakers of Working Group I of the *IPCC Fifth Assessment Report*).

Page 3—**more *and* bigger storms**: Emanuel, "Increasing Destructiveness," published in 2005, showed that hurricanes had intensified over the preceding three decades. The ensuing scientific debate seems to have settled with the conclusion that climate change does indeed lead to more intense hurricanes but that their frequency may not change (or may even go down slightly). Some of the latest research, Emanuel, "Downscaling CMIP5," finds that climate change will likely lead to both more intense *and* more frequent storms. That scientific debate isn't settled, yet the physical signs are sadly clear. Projected economic impacts are similarly striking: Mendelsohn et al., "Impact of Climate Change," finds that "global hurricane damage will about double owing to demographic trends, and double again because of climate change" through 2100 (Emanuel, "MIT Climate Scientist Responds").

That said, hurricanes are still among the most difficult weather events to link to climate change, largely because of their rarity. As our ability to forecast hurricanes improves, it will become increasingly easier to conduct event studies around hurricanes of the type already conducted for other extreme events. (See the following note on "attribution science.")

Page 4—**attribution science**: A good starting point is the IPCC's 2012 *Special Report: Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation*. The study reports mixed evidence around today's extreme events but increasingly certain evidence going forward. There are also increasingly detailed studies of single events, perhaps most prominently by Peter Stott, who leads the Climate Monitoring and Attribution team at the UK Met Office. Stott, Stone, and Allen, "Human Contribution," draw the conclusions mentioned in the text, a doubling of the risk of a heat wave of the magnitude observed in Europe in 2003. Stott et al., "Attribution of Weather," surveys the recent literature and points to a way forward for attribution science.

A slew of other papers, many from the Met Office's Climate Monitoring and Attribution team, highlight the contributions of the rapidly developing field of "attribution science": Christidis et al., "HadGEM3-A Based System for Attribution," finds that the 2010 heat wave in Moscow can be attributed, at least in part, to human-caused climate change. The study compares a model run with observational data with estimates of what those data would be without anthropogenic forcings. Rahmstorf and Coumou, "Increase of Extreme Events," develop a method to determine the effect long-term trends have on the number of climate extremes. They use their approach to estimate that there is an 80 percent chance that the 2010 Moscow heat record would not have occurred without climate change. Otto et al., "Reconciling Two Approaches," contrasts these findings around increased odds with another study that finds no human fingerprint on the magnitude of the Moscow heat wave. Lott, Christidis, and Scott, "East African Drought," find that anthropogenic forcings increased the probability of the 2011 East African drought. Pall et al., "Flood Risk," uses a "probabilistic event attribution framework" to find that human emissions increased the likelihood of the 2000 floods in England and Wales by anywhere from 20 percent to over 90 percent. Peterson, Stott, and Herring, "Explaining Extreme Events of 2011," use the Central England Temperature dataset and global climate models to look at the effect of anthropogenic forcings on the chances of six extreme events in the UK that year. Li et al., "Urbanization Signals," attributes differences in minimum winter temperatures in Northern China cities to urbanization effects.

Some others look at the global links between warming and extreme events. Coumou, Robinson, and Rahmstorf, "Global Increase," look at the rising likelihood of record-breaking monthly-mean temperatures due to climate change. Their verdict: "Under a medium global warming scenario, by the 2040s we predict the number of monthly heat records globally to be more than 12 times as high as in a climate with no long-term warming." Also see Coumou and Robinson, "Historic and Future Increase," which estimates the percent of global land area that can expect to experience extreme summer heat.

Page 5—**three to twenty years**: See Rosenzweig and Solecki, "Climate Risk Information," and Fischetti, "Drastic Action." Lin et al., "Physically Based Assessment," uses a combination of climate and hydrodynamic models to show that what are now 100-year floods may hit every three to 20 years by the end of the century.

Talke, Orton, and Jay, "Increasing Storm Tides," estimates the increased chance of annual seawall breaches today compared to the mid-1800s. Also see Kemp and Horton, "Historical Hurricane

Flooding," who look at the direct contribution of sea-level rise to hurricane flooding.

Page 5—**0.3 to 1 meters**: The range comes from Working Group I's Summary for Policymakers in the *IPCC Fifth Assessment Report*. It compares average global sea levels for 2081–2100 to 1986–2005. That number is significantly above the earlier estimates from the *IPCC Fourth Assessment Report*. (See "left it out" on page 11.) It also updates (and lowers) earlier high estimates by the U.S. Army Corps of Engineers, which operates with a high scenario of 1.5 meters (5 feet) ("Incorporating Sea-Level Change Considerations in Civil Works Programs"), and by the National Oceanic and Atmospheric Administration (NOAA), which uses 2 meters (6.6 feet) as its high scenario for 2100 (Parris et al., "Global Sea Level Rise Scenarios").

Page 5—**no replacement**: Gillett et al., "Ongoing Climate Change," argues that if "rapid melting of the West Antarctic ice sheet . . . were driven by ocean warming at intermediate depths, as is thought likely, a geoengineering response would be ineffective for several centuries owing to the long delay associated with subsurface ocean warming." A full melting of the West Antarctic ice sheet would lead to about 3.3 meters (11 feet) of sea-level rise. (See "Melting of Greenland" on page 56 in chapter 3.)

Page 6—**catastrophe**: Kolbert, *Field Notes from a Catastrophe*, is among the most eloquent accounts. For a seminal study on the definitions of "dangerous anthropogenic interference," see Ramanathan and Feng, "Avoiding Dangerous Anthropogenic Interference." For a seminal classification of "tipping elements in the earth's climate system," not all of them necessarily "catastrophic," see Lenton et al.'s eponymous study. The list includes the melting of Arctic summer sea ice, the melting of the Greenland ice sheet, the melting of the West Antarctic ice sheet, the shutoff of the Atlantic thermohaline circulation, increasingly intense El Niño / Southern Oscillation, changes to the Indian summer monsoon, and dieback of the Amazon rainforest. Assessments differ for many of these potential tipping elements, which makes their potential impacts all the more significant. (See our extensive discussion of uncertainty in chapter 3.)

Page 8—"**free-driver" effect**: See the "Free Drivers" entry on page 38 in chapter 2 for a more comprehensive definition. See the corresponding note for alternative uses in the academic literature on energy efficiency economics, where it describes a type of network effect.

Page 8—**Chinese soot**: Bradsher and Barboza, "Pollution from Chinese Coal"; Yienger et al., "Episodic Nature."

Page 9—**warmest in human history**: Despite these clear overall trends, some have invariably pointed to a so-called warming pause or hiatus this past decade, which has found resonance in the press. See, for example: Ogburn, "What's in a Name?," Ogburn, "Climate Change 'Pause' into Mainstream," and Voosen, "Provoked Scientists." For a comprehensive analysis of media coverage, see Greenberg, Robbins, and Theel, "Media Sowed Doubt." The latest research points to the fact that the drop in the rate of warming wasn't there in the first place, providing a number of insights that, put together, may even over-explain the drop ("Global Warming: Who Pressed the Pause Button").

Page 9—**National Climate Assessment**: See Melillo, Richmond, and Yohe, "Climate Change Impacts in the United States."

Page 9—**"The Coming Arctic Boom"**: Borgerson, "The Coming Arctic Boom."

Page 9—**decades of warming**: If greenhouse gas concentrations already in the atmosphere had been held at 2000 levels, we would still have been committed to a likely temperature rise of 0.3–0.9°C (0.6–1.6°F) by 2100 relative to 2000, with a best estimate of 0.6°C (1.1°F). That number comes from the *IPCC Fourth Assessment Report*, also cited in chapter 12 of the *IPCC Fifth Assessment Report*.

A complete halt in emissions would only very slowly decrease global temperature. Ramanathan and Feng, "Avoiding Dangerous Anthropogenic Interference," reviews work that shows how only about a quarter of the already baked-in global average warming has been realized so far. Coumou and Robinson, "Historic and Future Increase," finds that if we stopped emitting today, we would still be locked into a doubling of land area experiencing extreme summer heat by 2020, and a quadrupling of that area by 2040. Only after 2040 will the frequency and severity of heat waves depend greatly on our level of mitigation today.

Even "air capture" of carbon dioxide—taking carbon dioxide out of the atmosphere directly—has a considerable lag. Air capture, once implemented at scale, can slow the rate of further changes, but many of the intervening climatic changes will indeed be irreversible. (See "comes under various guises" on page 107 in chapter 5 as well as the "Bathtub" entry on page 30 in chapter 2.)

Page 9—**centuries of sea-level rise**: Meehl et al., "Relative Outcomes," finds that even under aggressive mitigation scenarios that stabilize temperatures, "sea-level rise cannot be stopped for at least the next several hundred years."

Two independent studies point to the eventual collapse of large parts of the West Antarctic ice sheet (Joughin, Smith, and Medley, "Marine Ice Sheet Collapse," and Rignot et al., "Widespread, Rapid Grounding Line Retreat"). It has already been clear that the West Antarctic ice sheet has been melting at an ever increasing rate. Shepherd et al., "A Reconciled Estimate," estimate the average yearly loss of mass in the West Antarctic ice sheet to be 38 billion tons from 1992 to 2000, 49 billion tons from 1993 to 2003, 85 billion tons from 2000 to 2011, and 102 billion tons from 2005 to 2010.

Also see "Melting of Greenland" on page 56 in chapter 3.)

Page 10—**excess carbon dioxide in the atmosphere**: Solomon et al., "Irreversible Climate Change." Results differ across scenarios, but a rough rule of thumb suggests that approximately 70 percent of the "peak enhancement level" over the preindustrial level of 280 ppm perseveres after 100 years of zero emissions, while approximately 40 percent of the peak increase over the preindustrial level of 280 ppm persevered after 1,000 years of zero emissions. Note that this refers to the net increase in carbon dioxide in the atmosphere, not the exact molecule. Archer et al., "Atmospheric Lifetime," discusses the two often confused definitions for carbon's "lifetime," and concludes that 20–40 percent of excess carbon levels remain hundreds to thousands of years ("2–20 centuries") after it is emitted. The oft-cited Bern Model calculates that 20 percent of carbon dioxide remains after 1,000 years (Joos and Bruno, "Short Description"). The latest IPCC consensus says that roughly 15 to 40 percent of excess carbon dioxide remains in the atmosphere for over 1,000 years (see the *IPCC Fifth Assessment Report* Working Group I's Summary for Policymakers). Each carbon dioxide molecule has a lifetime of anywhere between 50 to 200 years, according to the U.S. Environmental Protection Agency's "Overview of Greenhouse Gases: Carbon Dioxide Emissions." The precise number is under considerable scientific dispute and is surprisingly poorly understood (Inman, "Carbon Is Forever").

Page 10—**400 parts per million**: 400 ppm is the concentration of carbon dioxide. Concentrations of other greenhouse gases—including methane, nitrous oxide, and industrial gases—are well known, too, but converting them into carbon dioxide–equivalent terms is fraught with uncertainties, as it relies on a number of assumptions of relative radiative efficiency compared to carbon dioxide and the atmospheric lifetimes of the gases over time. Estimates of carbon dioxide–equivalent concentrations range from around 440 to as high as 480 ppm ("World Energy Outlook 2013," citing a 2010 estimate, and Butler and Montzka, "NOAA Annual Greenhouse Gas Index," citing a 2013 estimate, respectively). See also Monastersky, "Global

Carbon Dioxide Levels," for a more detailed account of reaching the 400 ppm milestone.

Adding in the relative cooling effects of various tiny human-made particles (aerosols), brings total global warming effects of all human-caused emissions down to closer to around 400 ppm. Hence the best proxy for the full effect of all human-caused emissions *today* is still around 400 ppm, though if and when the masking effect of cooling aerosols disappears, the impact is bound to rise—and perhaps dramatically so.

The difficulties around converting everything into carbon dioxide–equivalent metrics is one reason why the IPCC primarily presents the warming impacts of human-caused emissions in terms of radiative forcing. The *IPCC Fifth Assessment Report* Working Group I's Summary for Policymakers puts total human-caused radiative forcing relative to 1750 at about 2.29 W m^{-2}, a level that includes the negative 0.9 W m^{-2} forcing from aerosols.

Page 10—**Global average temperatures**: Chapter 5, "Information from Paleoclimate Archives," of the *IPCC Fifth Assessment Report* lays out these facts about the Pliocene environment. Temperatures were 2–3.5°C (3.6–6.3°F) above preindustrial levels.

Page 10—**camels lived in Canada**: Rybczynski et al., "Mid-Pliocene" reports evidence showing the existence of giant camels living in the Canadian High Arctic in the Pliocene era.

Page 10—**decades to centuries**: The technical distinction is between a so-called fast equilibrium and so-called earth system sensitivity. Although time here is relative: "Fast" applies in geological terms, over the course of decades and even a century or two. Over the course of centuries, other factors that influence the earth's reaction to higher atmospheric concentrations of carbon dioxide begin to play a role. Examples include albedo changes, changes in biological sinks such as oceans and terrestrial ecosystems, and temperature-induced releases of carbon and methane. See, for example: Hansen et al., "Target Atmospheric CO_2," and Hansen and Sato, "Climate Sensitivity." Previdi et al., "Climate Sensitivity in the Anthropocene," incorporates these long-term feedbacks into an estimate of earth system sensitivity and finds that it could be twice as high as estimates for climate sensitivity, at 6–8°C (11–14°F) per doubling of carbon dioxide. Although this extra warming would be on a much larger timescale, perhaps multiple millennia, the effects of some of the feedbacks could start to hit home within this century.

Page 11—**third of sea-level rise**: The observed sea-level rise from thermal expansion since 1993 has been about 1.1 mm per year, or

34 percent of the total observed rise of approximately 3.2 mm per year. The modeled contribution of thermal expansion is higher, at 1.49 mm per year since 1993. Chapter 13, "Sea Level Change," of the *IPCC Fifth Assessment Report*.

Page 11—**left it out**: The 2007 IPCC report included the effects only from thermal expansion in its projections for sea-level rise, not the effects of melting polar ice caps (Projections of Future Changes in Climate in Working Group I of the *IPCC Fourth Assessment Report*), an omission since corrected. The Summary for Policymakers in Working Group I of the 2013 *IPCC Fifth Assessment Report* has several scenarios for sea levels, all incorporating the melting ice caps that were left out in the 2007 estimates, and projects sea-level rise as high as 1 meter (3 feet) by 2100 without significant climate action. For a good account of the debate surrounding the latest IPCC report and this particular issue, see Clark, "What Climate Scientists Talk about Now." See also "0.3 to 1 meters" on page 5.

Page 11—**perhaps even pleasant**: Moderate warming may indeed come with real, monetizable benefits. Virtually alone among climate-economic models, Richard Tol's FUND model estimates positive global benefits for slow, moderate warming up to about 2°C (3.6°F). For much of the 20th century, Tol estimates, the benefits of global warming may have outweighed the costs (Tol, "Economic Impact of Climate Change"). For another take around the opportunities provided by a changing climate, see Kahn, *Climatopolis*.

The broader question around the economic costs and benefits of global warming engenders considerable—often extremely contentious—debate. Tol, "Correction and Update," surveys 21 estimates of the welfare impacts of various degrees of average global warming. Three of these estimates, most notably Tol's own ("Estimates of the Damage Costs"), show zero or positive economic impact of climate change. (Tol, "Estimates of the Damage Costs," estimates a significant positive welfare impact of 1°C (1.8°F) of global average warming to the tune of 2.3 percent of global welfare. Mendelsohn et al., "Country-Specific Market Impacts," presents two central welfare estimates for 2.5°C (4.5°F) of global average warming, with both showing close to zero impact.) One further estimate, with a negative central value, spans zero as part of its confidence interval. The other 17 estimates surveyed show economic costs, some of them significant, at various global average temperatures. Tol then proceeds to plot all 21 economic impacts and presents the central "least squares" curve, including 95 percent confidence intervals ("Correction and Update," figure 2). Revising his own earlier estimates (reproduced in "Correction and Update," figure 1), Tol estimates that the central curve showing global welfare impacts is negative for any amount of global average warming. Even the upper 95 percent confidence interval barely goes above zero, a clear departure from Tol's own earlier survey updated and corrected here.

We would also hasten to add that most every one of the 21 estimates presented in Tol, "Correction and Update," can represent only a lower bound for the true economic costs. See "possibly much more" on page 23 in chapter 1 and our extensive discussion throughout chapter 3, in particular around "$2 per ton" and "Nordhaus's preferred "optimal" estimate" on page 57 as well as "damages affect output growth *rates*" on page 63.

Significant negative effects on human society and ecosystems notwithstanding, adapting to low levels of global average warming is a broad phenomenon. That may even include coral reefs, often viewed as a poster child of negative impacts: many fish will migrate; corals, by and large, can't. The newest evidence instead points to coping mechanisms for some corals (Palumbi et al., "Reef Coral Resistance"). Even while coping with warmer temperatures, however, marine environments still have to deal with the detrimental effects from increased acidity. See "Ocean acidification" on page 42 in chapter 2.

Page 12—**increasing rate**: Chapter 2 in Working Group I of the *IPCC Fifth Assessment Report* finds that global mean surface temperature has increased by approximately 0.86°C (1.5°F) since 1901, with 0.72°C (1.3°F) or 81 percent of that warming occurring since 1951. The reported average from 1951 to 2012 is 0.106 to 0.124°C (0.19 to 0.22°F) per decade, while the 100-year average, from 1901 to 2012, is only 0.075 to 0.083°C (0.14 to 0.15°F) per decade, depending on the dataset used. The U.S. Environmental Protection Agency, "Climate Change Indicators in the United States: U.S. and Global Temperature," shows that since the 1970s, the rate of increase has been 0.17–0.25°C (0.31–0.45°F) per decade in the United States, versus 0.072°C (0.13°F) per decade since 1901.

Something similar holds for sea-level rise. Sea levels have risen by around 0.2 meters (0.7 feet) over the past century. And the trend has been accelerating: over the past hundred years, the average sea-level rise was at around 1.7 centimeters (0.7 inches) per decade; over the past forty years, it was around 2.0 centimeters (0.8 inches) per decade; over the past twenty years, it was about 3.2 centimeters (1.3 inches) per decade. That trend is likely only going to accelerate further for the foreseeable future. The IPCC estimate for 2100 ranges from 0.3 to 1 meters (1 to 3 feet) in average global sea-level rise is relative to today's levels, on top of the 0.2 meters (0.7 feet) already observed. See "0.3 to 1 meters" on page 5.

Page 12—**decade without warming**: See "warmest in human history" on page 9.

Page 12—**increase over land**: From 2000 to 2009, temperature change in the US has been 50 percent greater over land than over ocean (Carlowicz, "World of Change"). Globally, surface air temperatures over land are thought to have risen 0.25 to 0.27°C per decade since 1979, depending on the dataset used, versus only 0.12°C per decade over oceans (chapter 2 in Working Group I of the *IPCC Fifth Assessment Report*).

Page 12—**twice the global average**: Average warming over the Arctic is projected to be 2.2 to 2.4 times the global average through the end of the century (chapter 12 in Working Group I of the *IPCC Fifth Assessment Report*).

Page 13—**warmed by 0.8°C (1.4°F)**: The *IPCC Fifth Assessment Report* Working Group I's Summary for Policymakers states two central numbers: 0.85°C of global average surface temperature warming between 1880 and 2012, and 0.78°C between the averages from 1850 to 1900 and 2003 to 2012. The 90 percent confidence intervals around each are 0.65 to 1.06°C and 0.72 to 0.85°C, respectively.

Page 14—**700 ppm**: The IEA's "World Energy Outlook 2014" calls this scenario the "New Policies Scenario." If we follow this trajectory, where all current emissions reductions commitments are met, support for renewables deployment and energy efficiency measures continues at or near current levels, and the world phases out at least parts of its fossil fuel subsidies, we can expect that carbon dioxide–equivalent concentrations reach 700 ppm by 2100. The IEA translates that level to a total temperature increase from preindustrial levels of 3.6°C (6.5°F), a bit more than our median increase of 3.4°C (6.1°F).

The IPCC is much less committal as to where concentrations will go. *IPCC Special Report on Emissions Scenarios* creates four families of scenarios, for a total of 40 cases, based on different sets of assumptions about the way the future world will work. It does not assign a probability to any of the scenarios and makes no claims about their relative likelihood. In later Assessment Reports, the IPCC uses these scenarios to determine ranges of possible future greenhouse gas concentrations. Frighteningly, the scenarios lead to estimates up to 1,550 ppm of carbon dioxide–equivalent concentrations. The latest IPCC report isn't any more reassuring. Its modeled scenarios range from a peak at 500 ppm to 1,500 ppm, with likely associated temperature increases this century of between 0.3 and 4.8°C (*IPCC Fifth Assessment Report* Working Group I's Summary for Policymakers).

Page 14—**Mark Lynas**: Lynas, *Six Degrees.* He describes in frightening detail what kind of changes we can expect with temperature increases of 1–6°C, starting with the loss of coral reefs and ending with extreme resource shortages and mass migration.

Page 14—**HELIX**: Short for: High-End cLimate Impacts and eXtremes. The project began in November 2013. For more, see www.HELIXclimate.eu. The project description aims to provide "a set of credible, coherent, global and regional views of different worlds at 4, 6 and 2 degrees celsius."

Page 14—**around 10 percent**: See our discussion in chapter 3, in particular "clearly more room" on page 51 and "scientific papers" on page 53.

Page 14—**cognitive dissonance**: For the earliest work on cognitive dissonance and related phenomena, see Kahneman and Tversky, "Subjective Probability," Kahneman and Tversky, "Prospect Theory," and Kahneman, Knetsch, and Thaler, "Experimental Tests." Kahneman, *Thinking, Fast and Slow*, provides a comprehensive, accessible version, including its implications. For more on the psychology of climate change, see, among many others: Wagner and Zeckhauser, "Climate Policy."

Page 15—**giant bathtub**: Guy et al., "Comparing the Atmosphere to a Bathtub," conducted a study of the effectiveness of the bathtub analogy on increased understanding of carbon dioxide stabilization and one's preferred level of climate change mitigation. They found that the analogy can be effective in improving nonexperts' understanding of climate change. (They tested both undergraduate students and the Australian public.) The study also showed that using the analogy to explain carbon dioxide accumulation could lead to stronger support for climate action (in their test among undergraduate students). There is plenty of nuance, though. Words seem to help; graphs don't: "Our results show that analogy can improve non-experts' understanding of CO_2 accumulation but that using graphs to convey emissions rate information is detrimental to such improvements." For more on the bathtub analogy, see the "Bathtub" entry on page 30 in chapter 2.

Page 15—**More specifically**: Sterman, "Risk Communication." The specific question involved two graphs: One graph was given to test subjects and included a flat line for concentrations: "Consider a scenario in which the concentration of CO_2 in the atmosphere gradually rises to 400 ppm, about 8 percent higher than the level in 2000, then stabilizes by the year 2100." The second graph showed a rising trend line for emissions, asking students to fill in the future path of emissions to achieve stable concentrations. A surprising number of test subjects answered by stabilizing emissions instead of bringing them down to stabilize concentrations.

Page 15—**that won't happen**: Overall, net global uptake has doubled from about 8.8 to 18 billion tons of carbon dioxide per year between 1960 and 2010 (Ballantyne et al., "Increase in Observed Net Carbon Dioxide Uptake"). That comes out to about 50 percent of carbon dioxide emitted each year. In other words, the drain has increased because of the higher water pressure, even though the water is still rising. More recently, however, the rate of increase of uptake by oceans seems to have decreased, possibly hinting at a saturation point (Khatiwala, Primeau, and Hall, "Reconstruction of the History"). The same seems to hold for European forests (Nabuurs et al., "First Signs"). Reichstein et al., "Climate Extremes," points to significant caveats going forward.

Page 16—**latest IPCC report at the time**: See the Executive Summary of Working Group I in the *IPCC Fourth Assessment Report*.

Page 17—**declined by 80 percent**: Liebreich, "Global Trends." Lower manufacturing costs, rather than shorter-term stock liquidation, has caused much of the recent photovoltaic price reductions (Bazilian et al., "Re-considering the Economics of Photovoltaic Power").

Page 18—**50 percent of its electricity**: Kirschbaum, "Germany Sets New Solar Power Record."

Page 18—**5 percent of its electricity**: Photovoltaics accounted for 5 percent of total power consumption in Germany in 2013 (Franke, "Analysis"). It similarly accounted for 4.7 percent of total power consumption in 2013 ("Statistic Data on the German Solar Power [Photovoltaic] Industry").

Page 18—**looking up globally**: "China's 12GW Solar Market Outstripped All Expectations in 2013," and "Global Market Outlook for Photovoltaics 2013–2017." An important caveat here is that the impressive solar capacity growth masks relatively small capacity factors compared to traditional energy sources like fossil, nuclear, and hydro. Still—in keeping with the "optimism track"—increased generation follows a similar trend as increased capacity, and capacity factors are only going to improve going forward.

Page 19—**majority of the electorate**: It's true that the polls show general skepticism about the existence of climate change (see Marlon, Leiserowitz, and Feinberg, "Perspectives on Climate Change," where

97 percent of climate scientists versus 41 percent of the American public believe climate change is happening and caused by humans). Not surprisingly, Americans seem to be against many potential governmental actions to mitigate global warming, like a carbon tax (*Survey Findings on Energy and the Economy*). However, there are many pro-environment actions that a large majority (as high as 75 to 85 percent) of Americans polled would like to see. See Krosnick, "The Climate Majority," where data from the Political Psychology Research Group's poll of 2010 shows that Americans overwhelmingly support limitations on businesses' air pollution (86 percent), incentives or regulations to increase manufacturing of cars that use less gas (81 percent), appliances that use less electricity (80 percent), and buildings requiring less energy to heat and cool (80 percent). Moreover, young people overwhelmingly support climate legislation, according to a recent poll by the League of Conservation Voters (Benenson Strategy Group and GS Strategy Group). Eighty percent of voters under 35 support the president taking action on climate change. Over half of under-35 Republican voters would be less likely to vote for someone who opposed the President's Climate Action Plan. Finally, according to a Pew Research Center / USA Today survey, 62 percent of Americans are in favor of stricter emission limits on power plants. Americans on the whole are, however, less concerned about climate change than other countries surveyed by the Pew Research Center in the Pew Global Attitudes Project. Only 40 percent of Americans see global climate change as a major threat to their country. The global average for the 39 countries surveyed was 54 percent, the same as the percentage of Europeans who see climate change as a threat.

Page 19—**Technology is good**: Technological advances may accumulate at ever increasing rates for good reason. This may even provide a good explanation for the kind of idea-based growth that could allow for a more dematerialized future and sets growth the way economists typically describe it apart from material growth that ought to hit planetary limits. See Weitzman, "Recombinant Growth."

Page 19—**horse manure crisis**: The horse manure story has been told many times, perhaps most comprehensively by Eric Morris under the heading "From Horse Power to Horsepower," most prominently by Steven Levitt and Stephen Dubner in *SuperFreakonomics*, and most convincingly by Elizabeth Kolbert in a *New Yorker* review of the book's climate section ("Hosed"). Kolbert thankfully also clears up some of the misconceptions propagated by *SuperFreakonomics*.

This endnote thus far is fully taken from Wagner, *But Will the Planet Notice?* (which provides a further summary).

Page 20—**Nixon went on to sign**: Richard Nixon signed the National Environmental Policy Act of 1969 on January 1, 1970. It was the federal "Reorganization Plan No. 3" in July 1970 that led to the creation of the Environmental Protection Agency in December that year. Besides the acts listed, Nixon also signed the Federal Insecticide, Fungicide, and Rodenticide Act (1972), heavily amending the 1947 version that hadn't been very concerned with regulating pesticide use, the Noise Control Act (1972), and the Coastal Zone Management Act (1972). The official name of the "Clean Water Act" is the "Federal Water Pollution Control Act," which was amended in 1972.

Page 20—**local pollutants**: Axelrad et al., "Dose-Response Relationship," among many other studies, finds prenatal exposure to mercury correlates to loss of IQ (around .18 decrease in IQ per 1ppm increase in maternal hair mercury) by surveying the data from three previous studies. Brauer et al., "Air Pollution" finds a positive association between a child's exposure to soot, among other traffic-related air pollutants, and that child's risk of developing asthmatic and allergic symptoms as well as respiratory infections. Many early studies looked at what ingredients in smog are most inductive of eye irritation. See Altshuller, "Contribution of Chemical Species," and Haagen-Smit, "Los Angeles Smog." Long-term exposure to ozone in the troposphere, an essential ingredient of smog, has been linked to increased mortality rates. (Jerrett et al., "Ozone Exposure and Mortality"). The U.S. Safe Drinking Water Act authorizes the EPA to set standards for contaminants found in drinking water for good reason. See the U.S. EPA site for Drinking Water Contaminants (http://water.epa.gov/drink/contaminants/) for updated maximum permissible levels of contaminants, and more information of the health effects of different contaminants.

Page 20—**Niccolò Machiavelli**: The quote comes from Chapter VI of Machiavelli, *The Prince*, first distributed around 1515 and then published posthumously in 1532.

Page 21—**death**: Miller, *Coal Energy Systems*, and Rottenberg, *In the Kingdom of Coal*.

Page 21—**how people behave**: Refer back to "cognitive dissonance" on page 14. Moreover, collective action is particular difficult in the presence of persistent uncertainties. See Barrett, "Climate Treaties," which shows this point theoretically. Barrett and Dannenberg, "Climate Negotiations," and Barrett and Dannenberg, "Sensitivity of Collective Action," confirm it experimentally.

Page 22—**greenhouse effect**: See the "Climate Science" entry on page 35 in chapter 2.

Page 22—**around 940** *billion* **tons**: See "tons of carbon dioxide" on page 93 in chapter 5.

Page 22—**2 ppm**: Rate of increase from CO_2Now (http://co2now.org /Current-CO2/CO2-Trend/acceleration-of-atmospheric-co2.html), calculated using source data from Keeling et al., Exchanges of atmospheric CO_2. In the past decade (2000 to 2010), greenhouse gas emissions have increased, on average, 2.2 percent a year, faster than during the three decades before 2000 (Summary for Policymakers of Working Group III of the *IPCC Fifth Assessment Report*). Carbon dioxide emissions from fossil fuel combustion and cement production alone have increased by 2.5 percent a year on average in the past decade (Friedlingstein et al., "Persistent Growth of CO_2 Emissions.")

Decadal averages may mask more recent changes in the trend. In 2012, for example, global carbon dioxide emissions rose by less than they had in an average year during the previous decade (and that despite the global recession of the late 2000s). Put differently, the increase in the increase in concentrations decreased in 2012. However, emissions still rose by around 1.4 percent (Olivier et al., "Trends in Global CO_2 Emissions"). Moreover, the hopeful trend did not continue in 2013, where emissions are projected to have risen 2.1 percent from 2012 (Le Quéré et al., "Global Carbon Budget 2013.")

Even if we slow the increase, stabilizing emissions (the inflow) will be far from enough. We need to stabilize (and eventually decrease) concentrations, the levels. Refer back to the earlier section on "The Bathtub Problem," beginning on page 15, and the "Bathtub" entry on page 30 in chapter 2.

Page 22—**billion or so high-emitters**: Chakravarty et al., "Sharing Global CO_2 Emission Reductions."

Page 22—**$500 billion per year**: See "World Energy Outlook 2014" for the latest country-specific numbers. The latest report puts the total at $548 billion in 2013, a $25 billion cut from the prior year. It also mentions that many countries are making moves to decrease their subsidies. Still, fossil fuel subsidies are over four times as high as subsidies for renewables. Meanwhile, global carbon dioxide emissions are at over 30 billion tons (World Resource Institute's Climate Analysis Indicators Tool). That averages out to subsidies of over $15 per ton of carbon dioxide. See Clements et al., *Energy Subsidy Reform*, for further estimates ($480 billion in 2011 for total energy subsidies) as well as "lessons and implications."

Contrast those subsidies with implicit carbon dioxide prices in certain countries due to other forms of regulation. Vivid Economics, "Implicit Price of Carbon," calculates the implicit carbon dioxide price in the electricity sectors in Australia, South Korea, China, Japan, the UK, and the United States. The price ranges from $0.50 per ton in South Korea, to 28.46 in the UK. The price in the United States is estimated to be around $5 per ton of carbon dioxide, roughly equal to total direct and indirect U.S. fossil fuel subsidies of around $3 per ton of carbon dioxide (OECD, "Fossil Fuel Subsidies," estimates that U.S. fossil fuel subsidies add up to around $16.3 billion in 2010).

Table 3 in Aldy and Pizer, "Comparability of Effort in International Climate Policy Architecture," presents carbon dioxide prices under various countries' energy and climate policies, ranging from the cap-and-trade program under the U.S. Regional Greenhouse Gas Initiative (RGGI) with a price of below $3 to German solar feed-in-tariffs estimated to be over $750 per ton of carbon dioxide abated.

Page 23—**stopped fuel subsidies**: "Nigeria Restores Fuel Subsidy to Quell Nationwide Protests."

Page 23—**Pigouvian taxes**: Pigou himself, it turns out, wrote about rabbits, not pollution: "incidental uncharged disservices are rendered to third parties when the game-preserving activities of one occupier involve the overrunning of a neighbouring occupier's land by rabbits—unless, indeed, the two occupiers stand in the relation of landlord and tenant, so that compensation is given in an adjustment of the rent." (Pigou, *The Economics of Welfare*.) But the principle is the same.

While Pigouvian taxes are, in fact, the efficient policy instrument, they also open up questions of redistribution. See, for example, Sterner, *Fuel Taxes*, which addresses questions of redistribution in the context of gasoline taxes.

Page 23—**possibly much more**: The precise numbers presented in the first table of the "Technical Update of the Social Cost of Carbon for Regulatory Impact Analysis under Executive Order 12866" for a ton of carbon dioxide emitted in 2015, using a 3 percent social discount rate, is $37. For 2020, the number is $43; for 2030, the number increases to $52. All figures are in inflation-adjusted 2007 dollars. The $37 figure would be much closer to $40 in today's dollars. The increase from $37 to $43 and $52 emphasizes the point that the damage caused by carbon dioxide is because of the concentration already in the atmosphere. The more is already there, the more marginal damage each additional unit causes.

This document referenced here represents the most recent update by the U.S. government, published November 1, 2013, and it marks a significant increase from figures published only three years prior. Back then, the central estimate of the social cost of carbon was $24 for a ton of carbon dioxide emitted in 2015. Table 1 of "Technical Update" summarizes the key factors that have led to the increase of the social cost between the 2010 and 2013 iterations. For DICE, those were "updated calibration of the carbon cycle model and explicit representation of sea level rise (SLR) and associated damages."

Also see Greenstone, Kopits, and Wolverton, "Developing a Social Cost of Carbon," for a detailed description of the original Interagency Working Group process that arrived at the 2010 estimate. In short, the U.S. government's social cost of carbon calculations are the result of a multiyear, multiagency review process, based on three well-established economic models. Among the most prominent such models is DICE, from Bill Nordhaus at Yale. For more on Nordhaus's model, see the "DICE" entry on page 36 in chapter 2 and the discussion around "$2 per ton" and "Nordhaus's preferred "optimal" estimate" on page 57 in chapter 3.

For a detailed analysis of specific model shortcomings, see Kopp and Mignone, "Social Cost of Carbon Estimates." Van den Bergh and Botzen, "Lower Bound," argue for a social cost of at least $125 per ton of carbon dioxide. For a critique of integrated assessment models in general, see two prominent examples: Pindyck, "Climate Change Policy: What Do the Models Tell Us?" and Stern, "Structure of Economic Modeling." Pindyck's answer to the question posed in his title: "very little." Stern is similarly cautious about saying that economic models can tell us the full story. Both Pindyck and Stern, though, conclude that the Interagency Working Group's U.S. Social Cost of Carbon of around $40 per ton of carbon dioxide would be a good starting point. Stern declares it "far better than zero." Finally, for an argument tying social cost calculations to fat tails, the subject of chapter 3, see Weitzman, "Fat Tails and the Social Cost of Carbon."

Page 23—**35 cents per gallon**: The EPA estimates that each gallon of gasoline combusted produces on average 0.00892 metric tons of carbon dioxide. At $40 per ton, that is 35.68 cents per gallon. "Clean Energy: Calculations and References."

Page 24—**cap and trade**: Cap and trade was first introduced by Dales, *Pollution, Property, and Prices*. The United States used cap and trade to help remove chlorofluorocarbons in compliance with the Montreal Protocol, for getting lead out of gasoline, and, perhaps most prominently, for cutting sulfur dioxide from U.S. smokestacks in an effort to combat acid rain.

Page 24—**exact same result**: See Weitzman, "Prices vs. Quantities," for a theoretical argument around minimizing welfare losses under uncertainty. Newell and Pizer, "Regulating Stock Externalities under Uncertainty," extends the result by considering the case of a stock pollutant like carbon dioxide.

Page 24—**epic debates**: For a recent academic debate on taxes versus caps, see Keohane, "Cap and Trade, Rehabilitated" for the pro-cap argument, and Metcalf, "Designing a Carbon Tax," for the pro-tax argument. For a review of the debate, see Goulder and Schein, "Carbon Taxes vs. Cap and Trade."

Page 24—**cap and trade limits emissions**: See Keohane and Wagner, "Judge a Carbon Market."

Page 25—**lower compliance costs**: See, among others, Meng, "Estimating Cost of Climate Policy."

Page 25—**countervailing the force**: See Weitzman, "Negotiating a Uniform Carbon Price."

Page 27—**Electricity grid reform**: Harvard's Bill Hogan is a pioneer of this work. See, for example, Hogan, "Scarcity Pricing." For a good survey of grid reform more broadly, see Fox-Penner, *Smart Power*.

Page 27—**how cost-effective**: Karplus et al., "Vehicle Fuel Economy Standard," looks at fuel economy standards in comparison to and combination with emissions constraints. They estimate that the new U.S. CAFE standards will cost 6–14 times more than the fuel tax that would reach the same reduction in gas use. See also Fischer, Harrington, and Parry, "Automobile Fuel Economy Standards," for a good survey. See Jacobsen, "Evaluating U.S. Fuel Economy Standards," and Klier and Linn, "New-Vehicle Characteristics," for recent cost estimates of meeting CAFE targets. For a review of the effect of gasoline taxes, see Sterner, *Fuel Taxes*.

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Page 31—**5 parts per million (ppm)**: For the original data, see the Mauna Loa Observatory's data at http://www.esrl.noaa.gov/gmd/obop/mlo/. Also see "2 ppm" on page 22 in chapter 1.

Page 31—**700 ppm**: see "700 ppm" on page 14 in chapter 1.

Page 31—**400 ppm**: See "400 parts per million" on page 10 in chapter 1.

Page 32—**Some companies**: See Gunther, *Suck It Up*.

Page 32—**more expensive**: One flavor of this technology may have the potential to reverse the equation, at least in the narrow sense of those removing carbon: captured carbon dioxide could be piped underground to aid in pumping more oil. That comes under the term "enhanced oil recovery," and it turns captured carbon dioxide into a potentially valuable commodity. The irony—if that's the right term—is that it also leads to even more emissions.

Page 32—**Or maybe not**: The planet is experiencing unprecedented levels of technological progress, and for good reason (see, for example, Weitzman, "Recombinant Growth"). Morris, *Why the West Rules—for Now*, uses this fact to end his book on a debate that steers clear from his title question of whether the West, or China, will rule the future. Instead, Morris talks about the choice between "Singularity" and "Nightfall": how to avoid existential risks like climate change and navigate away from "Nightfall" and toward "Singularity."

Page 33—**linked to carbon dioxide**: See, for example, Shoemaker and Schrag, "Overvaluing Methane's Influence," and Solomon et al., "Atmospheric Composition." See also "decades of warming" and "excess carbon dioxide in the atmosphere" on pages 9 and 10, respectively, in chapter 1.

Page 34—**capping or taxing**: For the intricate yet often important differences between the two, see the debate on cap and trade versus taxation beginning on page 24 in chapter 1.

Page 34—**hit the mark**: See van Benthem, Gillingham, and Sweeney, "Learning-by-Doing."

Page 34—**fossil fuel subsidies**: See "$500 billion per year" on page 22 in chapter 1.

Page 35—**means subsidies**: For one of the best and most comprehensive arguments for a dual price-subsidy approach, see Acemoglu et al., "The Environment and Directed Technical Change."

Page 35—**discovered: 1824**: In the 1820s, Joseph Fourier calculated that, considering its distance from the sun, the earth should be much cooler than it is. Among other possible reasons for the extra heat, Fourier suggested that the atmosphere might somehow act as an insulator. (Fourier, "Remarques generals." The paper was republished three years later, with slight modifications: Fourier, "Les Temperatures.")

Page 35—**shown in a lab: 1859**: John Tyndall took Fourier's work a step further, when he began his lab experiments in January 1859 ("John Tyndall"). The seminal paper showing that gasses, including water vapor and carbon dioxide, could trap heat in the atmosphere was published in 1861 (Tyndall, "On the Absorption and Radiation of Heat").

Page 35—**quantified: 1896**: Svante Arrhenius first demonstrated the greenhouse effect and calculated climate sensitivity—what happens to temperatures as concentrations of carbon dioxide double—in 1896 (Arrhenius, "On the Influence of Carbonic Acid"). Arrhenius calculated climate sensitivity to be 5–6°C (9–11°F), larger than current consensus estimates of between 1.5 and 4.5°C (2.7 and 8.1°F), established in the 1970s (Charney et al., "Carbon Dioxide and Climate"). See the extensive discussion on climate sensitivity in chapter 3 for more.

Page 35—**Climate Sensitivity**: "Climate sensitivity" or "equilibrium climate sensitivity" is widely defined as the global average surface equilibrium temperature warming from a doubling of atmospheric carbon dioxide concentrations. It is inherently a long-run estimate, how temperatures will react over many decades or centuries, in "equilibrium." In geological times, this still counts as "fast." See "decades to centuries" on page 10 in chapter 1 on the distinction between "fast equilibrium"—what is captured by most commonly used climate sensitivity parameters—and so-called earth system sensitivity, which could be over double the prevailing climate sensitivity estimate. Climate sensitivity ranges are typically pieced together from various estimates: actual temperatures measured by instruments over the past 150 or so years; paleoclimatic evidence from glacial and other developments over the past millions of years; carefully calibrated climate models; and a host of other means like evidence from volcanic eruptions or simple expert elicitation (asking climate scientists about their best guesses). For a comprehensive review, see Knutti and Hegerl, "Equilibrium Sensitivity."

See chapter 3 on "Fat Tails" for the history of climate sensitivity calculations and the profound implications.

Page 36—**DICE**: Bill Nordhaus first introduced DICE in 1991. A later derivation, RICE, includes regional differences. See, for example, Nordhaus, "To Slow or Not to Slow," and, most prominently, Nordhaus, "Optimal Transition Path." For the most comprehensive description at the time, see Nordhaus, "Optimal Greenhouse Gas Reductions." The latest and most comprehensive description of his work is in Nordhaus, *Climate Casino*. For a later update, see Nordhaus, "Estimates of the Social Cost of Carbon," which arrives at a price of $18.6 per ton of carbon dioxide emitted in 2015 (in 2005 dollars). For further in-depth discussion see "possibly much more" on page 23 in chapter 1 and the discussion on page 57 in chapter 3, around "$2 per ton" and "Nordhaus's preferred 'optimal' estimate."

Page 35—**Free Drivers**: Our definition and subsequent use of the term solely focuses on the context of geoengineering. Others have used the term in the context of energy-efficiency improvements, referring to a type of network effect, and a highly positive one at that: those outside a particular energy-efficiency program may adopt the more efficient technology because they feel compelled to do so by participants in the program. See, for example, Gillingham, Newell, and Palmer, "Energy Efficiency Economics."

Page 38—**Mount Tambora**: Stothers, "The Great Tambora Eruption," estimates a mean temperature decrease in the Northern Hemisphere of 0.4–0.7°C (0.7–1.3°F). For a more detailed description of the eruption and its diverse range of consequences, see Klingman and Klingman, *The Year without a Summer*, and Stommel, *Volcano Weather*.

Page 39—**heart of the global problem**: For one of the first and the most widely cited explorations of the subject, see Hardin, "Tragedy of the Commons."

Page 40—**centuries and millennia**: See "excess carbon dioxide in the atmosphere" on page 10 in chapter 1.

Page 41—**over 10 meters**: See "Melting of Greenland" on page 56 in chapter 3.

Page 41—**10 percent**: See, for example, McGranahan, Balk, and Anderson, "The Rising Tide"; Anthoff et al., "Global and Regional Exposure"; Rowley et al., "Risk of Rising Sea Level."

Page 41—**one seeming exception**: Jensen and Miller, "Giffen Behavior and Subsistence Consumption."

Page 42—**Ocean Acidification**: The report "Economics of Ocean Acidification," from an International Atomic Energy Agency international workshop in 2012, provides an overview of the economic impacts of ocean acidification, while IGBP, IOC, SCOR, "Ocean Acidification Summary for Policymakers," discusses the science of the phenomenon. For a good summary of both, see "Acid Test." For more on the marine die-off 56 million years ago, see Thomas, "Biogeography of the Late Paleocene." There was no associated mass die-off in the terrestrial biosphere. Cui et al., "Slow Release of Fossil Carbon," shows how the peak rate of carbon dioxide release into the atmosphere around 56 million years ago was much lower than today.

Page 42—**alkalinity addition**: See Harvey, "Mitigating the Atmospheric CO_2 Increase," for a comprehensive discussion of directly adding limestone powder to oceans. See Rau, "CO_2 Mitigation," for a different method that involves first capturing carbon dioxide on land before releasing the alkaline solution into the ocean. Royal Society, "Geoengineering the Climate," includes a brief discussion and puts it in the larger context.

Page 44—**60 percent of global emissions**: Calculated for 2010, using the World Resource Institute's Climate Analysis Indicators Tool.

Page 44—**Books**: Sunstein's "Of Montreal and Kyoto," and the later adaptation in Sunstein, *Worst-Case Scenarios*, provide a comparative history and analysis of the Montreal and Kyoto Protocols. He suggests a few reasons for why the former worked so well while the latter has at best led to small steps in the right direction. In particular, Sunstein makes a strong case that success of the one, and the failure of the other, had a lot to do with domestic benefit-cost analysis in the United States. For a terrific insider's view on the making of the Montreal Protocol, see Benedick, *Ozone Diplomacy*. Barrett, *Environment and Statecraft*, uses, in part, the success of the Montreal Protocol to develop a theory on international environmental treaties, and what makes them work, or, in most cases, fail.

CHAPTER 3. FAT TAILS

Page 48—**more likely than not**: The IPCC attempts to assign plain-English terms to its consensus assessments: "more likely than not" corresponds to a likelihood of greater than 50 percent; "likely" corresponds to greater than 66 percent (not two-thirds; i.e. 67 percent); "very likely" corresponds to greater than 90 percent; "extremely likely" corresponds to greater than 95 percent. These terms were used to describe the likelihood of man-made global warming in, respectively, the IPCC's Second, Third, Fourth, and Fifth Assessment Reports. According to Engber, "You're Getting Warmer," an early draft of the Fourth Assessment Report called for the highest category, "virtually certain," which corresponds to greater than 99 percent probability, before settling at "very likely." Engber discusses the history and implications of the IPCC's probability assessments. For the latest formal guidance document, see Mastrandrea et al., "IPCC AR5 Guidance Note." For more on the history and the scientific underpinnings, see Giles, "Scientific Uncertainty." For a survey of how these probabilistic statements are perceived (and often misconstrued), see Budescu et al., "Interpretation of IPCC."

Page 48—**decade 'without warming'**: For more on the warming "pause" or "hiatus" of recent years, see "warmest in human history" on page 9 in chapter 1.

Page 48—**back to the 1800s**: See "Climate Science" on page 35 in chapter 2. For more on the history, and the future, see Roston, *The Carbon Age*.

Page 49—**Wally Broecker**: Broecker, "Climatic Change."

Page 49—**climate sensitivity**: See "Climate Sensitivity" on page 35 in chapter 2.

Page 49—**well-established facts**: Stocker, "Closing Door," and Matthews et al., "Proportionality of Global Warming," are among the latest to discuss the proportional relationship between total warming and cumulative emissions.

Page 50—**400 ppm**: This is the concentration of carbon dioxide. Counting other greenhouse gases (without aerosols), concentrations are between 440 and 480 ppm of carbon dioxide–equivalent greenhouse gases, depending on the source. See "400 parts per million" on page 10 and also "2 ppm" on page 22 in chapter 1.

Page 50—**700 ppm**: See "700 ppm" on page 14 in chapter 1.

Page 50—**Ad Hoc Study Group**: Charney et al., "Carbon Dioxide and Climate."

Page 50—**academic genius**: Gavin Schmidt tells the story on Real Climate.org, an excellent repository of the latest on climate change science (Schmidt and Rahmstorf, "11°C Warming").

Page 50—**the "likely" range**: By 1990 the IPCC range was still 1.5–4.5°C (2.7–8.1°F). Ditto by 1995 and 2001. By 2007, the range narrowed somewhat, though in the wrong direction. It seemed that 1.5°C (2.7°F) was no longer in the cards. The new "likely" range was 2–4.5°C (3.6–8.1°F). By 2013, the most recent IPCC Assessment report, the range widened again right back to where it's been all along: 1.5–4.5°C (2.7–8.1°F). For the relevant sections of the reports, see Working Group 1, chapter 5, of the *IPCC First Assessment Report*, Section B: Climate Modelling, Climate Prediction and Model Validation, of the *IPCC Climate Change 1992* Supplementary Report, Working Group I of the *IPCC Second Assessment Report*, Working Group I of the *IPCC Third Assessment Report*, Working Group I of the *IPCC Fourth Assessment Report*, and Working Group I of the *IPCC Fifth Assessment Report*.

It is true that the confidence in the range has increased markedly over time. Specifically, "confidence today is much higher as a result of high quality and longer observational records with a clearer anthropogenic signal, better process understanding, more and better understood evidence from paleoclimate reconstructions, and better climate models with higher resolution that capture many more processes more realistically" (Working Group I of the *IPCC Fifth Assessment Report*, TFE.6; also see Box 12.2). Still, the IPCC chose to call the range "likely" (>66 percent confidence) rather than opt for a more certain assessment such as "very likely" (>90 percent).

Things may even be worse than before for another reason. In 1990, the IPCC ventured a "best guess" of 2.5°C (4.5°F) within the wider range. By 2007, the "most likely" quantity was 3°C (5.4°F). Not certainty, not even an actual "mean" or "median" in statistical terms, but at least a single number—albeit a high one—around which to rally. By 2013, the IPCC issued no verdict as to which quantity would be most likely. That's a step back in sureness. The IPCC did add other caveats, notably a less than 5 percent probability of climate sensitivity being below 1°C and a less than 10 percent probability of above 6°C. See "clearly more room" on page 51 as well as "more likely than not" on page 48 for a definition of the "likely" range itself.

Page 51—**defines "likely"**: See "more likely than not" on page 48 as well as prior note.

Page 51—**clearly more room**: The IPCC's latest assessment report goes into a bit more detail: it describes anything below 1°C as "extremely unlikely" (0–5 percent) and anything above 6°C as "very unlikely" (0–10 percent) (Summary for Policymakers of Working Group I in the *IPCC Fifth Assessment Report*). The second row of this table translates the IPCC's statements into actual probabilities for different climate sensitivities:

Climate sensitivity	*<0°C*	*<1°C*	*<1.5°C*	*<>2.6°C*	*>3°C*	*>4.5°C*	*>6°C*
IPCC (2013)	No data	0–5%	("likely" between 1.5–4.5°C)				0–10%
Our calibration	0%	1.7%	11% (78% probability of between 1.5–4.5°C)	50%	37%	11%	3.1%

We calibrated a log-normal distribution by calculating an 11 percent probability of being greater than 4.5°C and an 11 percent probability of being below 1.5°C. Doing so interprets the IPCC's numbers as conservatively as possible. The IPCC, for example, states that any figure above 6°C would be "very unlikely." That implies a 0–10 percent range—5 percent, if we take a point estimate. However, if the IPCC authors wanted to say that it was, in fact, only 5 percent, they could have chosen to say "extremely unlikely." By saying "very unlikely," they, in effect, may have intended to ascribe a probability of between 5 and 10 percent—7.5 percent as the point estimate. Either way, our calibration arrives at a probability estimate of slightly over 3 percent for the chance of climate sensitivity being greater than 6°C, a "conservative" estimate for the purposes of our exercise that remains much below 7.5 percent.

Our interpretation of the "likely" range uses a similar logic: The IPCC definition of "likely" is between 66 and 100 percent. However, if the authors wanted to convey that the probability of being in the 1.5–4.5°C range was higher than 90 percent, they could have chosen to call the range "very likely." (In fact, "very likely" does have a firm definition in the guidance document for IPCC authors, while "extremely likely" is an additional term added by the authors involved in Working Group I of the *IPCC Fifth Assessment Report* (see Working Group I's Summary for Policymakers). For comparison, see Mastrandrea et al., "IPCC AR5 Guidance Note." Instead, the IPCC authors opted for the looser interpretation of "likely," which leads us to believe that the true likelihood may not be between 66 and 100 percent but between 66 and 90 percent. We split the difference and use 78 percent with 11 percent probability of being below the likely range and 11 percent probability of being above the likely range.

Our median estimate is 2.6°C (3.9°F). The most commonly cited mean climate sensitivity, 3°C (5.8°F), is therefore closer to the two-thirds mark in our calibration: we assume a 63 percent probability of climate sensitivity being below 3°C (5.8°F) and, conversely, a 37 percent probability of climate sensitivity being above 3°C (5.8°F). The latter is the probability mentioned in the table. The remaining estimates are in the bottom row of the table above.

Recent papers in *Science* and *Nature* have made the argument that climate sensitivity is much more likely above 3°C than below it. Fasullo and Trenberth, "A Less Cloudy Future," finds that models with lower climate sensitivities do not fully take into account albedo from changing cloud cover. Sherwood, Bony, and Dufresne, "Spread in Model," takes this idea further, and posits that accurate accounting of the cloud mixing processes suggests a climate sensitivity greater than 3°C (5.8°F).

Page 51—**bottle of Champagne**: A lot of analysis has gone into discovering the delicate science behind a good bottle of champagne. The average 750 ml bottle contains 9 grams of carbon dioxide, and emits about five liters once opened (Liger-Belair, Polidori, and Jeandet, "Science of Champagne Bubbles"). Not to mention the 200,000 metric tons released each year transporting the bubbly around the world (Alderman, "A Greener Champagne Bottle"). One way to minimize the loss of dissolved carbon dioxide in your champagne is to pour it like you would a beer—down the side of the glass instead of right to the bottom. It may not be quite as sophisticated, but scientists assure it will make for a better taste (Liger-Belair et al., "Losses of Dissolved CO_2"). Ironically, the celebratory champagne might not taste as nicely as it would if we had no cause for celebration at all. Wine quality in the Champagne region of France is, in fact, expected to increase based on projected climate change (Jones et al., "Global Wine Quality").

Page 52—**fat tail**: The technical definition of a "fat tail" is a distribution that approaches zero polynomially or slower. Conversely, the technical definition of a "thin tail" is a distribution that approaches zero exponentially or faster. A log-normal distribution, which we use, is in between thin and fat tailed. Some definitions call it "heavy tailed": no longer thin, but not yet fat either. Log-normal distributions approach zero faster than polynomially but slower than exponentially. All that means that our calibration is more conservative than the IPCC's own numbers, as it points to a chance of slightly above 3 percent of climate sensitivity being above 6°C. That compares to the IPCC's stated "very unlikely" range of anywhere between 0 and 10 percent. See "clearly more room" on page 51.

Page 53—**scientific papers**: The conceptual starting point for calculations leading up to this table is Weitzman, "Modeling and Interpreting the Economics." A further elaboration is found in Weitzman, "Fat-Tailed Uncertainty." A version resembling this table, with calculations for three different probability distributions but based on the *IPCC Fourth Assessment Report*, appeared in Weitzman, "GHG Targets as Insurance." The version here is based on fitting a log-normal probability distribution to climate sensitivity, as described in "clearly more room" on page 51:

CO_2e concentration (ppm)	*400*	*450*	*500*	*550*	*600*	*650*	*700*	*750*	*800*
Temperature increase for mean climate sensitivity (=3°C)	1.5°C	2.1°C	2.5°C	2.9°C	3.3°C	3.6°C	4.0°C	4.3°C	4.5°C
Temperature increase for median climate sensitivity (=2.6°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
Chance of >6°C, given 2–4.5°C "likely" range (with 70% probability)	0.03%	0.3%	1.3%	3.3%	6.3%	10.2%	14.4%	19.2%	23.9%

CO_2e concentration (ppm)	*400*	*450*	*500*	*550*	*600*	*650*	*700*	*750*	*800*
Chance of >6°C, given 1.5–4.5°C "likely" range (with 70% probability)	0.2%	1.1%	2.8%	5.2%	8.1%	11.3%	14.6%	18.0%	21.3%
Chance of >6°C, given 1.5–4.5°C "likely" range (with 78% probability)	0.04%	0.3%	1.2%	2.7%	4.9%	7.6%	10.6%	13.9%	17.3%

Row 1 has concentrations of ultimate carbon dioxide–equivalent (CO_2e) concentrations. Row 2 shows final temperature increases based on these concentrations and an assumed climate sensitivity of 3°C, the median figure found from a calibration to the 2007 *IPCC Fourth Assessment Report* "likely" range of 2–4.5°C. Row 3 shows the temperature increase for an assumed climate sensitivity of 2.6°C, the median figure found for our "best" log-normal calibration to the 2013 *IPCC Fifth Assessment Report* "likely" range of 1.5–4.5°C. The latter is also what we present in the main text. Note that this single "most likely" temperature increase is below the average or expected figure. That's because the distribution fitted around the IPCC "likely" range for climate sensitivity is assumed to be an asymmetric log-normal distribution, which cuts off at zero but has a long upward tail. Despite the uncertainties, no one would seriously argue that climate sensitivity should have a negative realization. The next three rows present various assumptions around the IPCC "likely" range: Row 4 assumes the old climate sensitivity range of 2–4.5°C, the recent consensus before the release of the *IPCC Fifth Assessment Report* in 2013. Row 5 widens the "likely" range to extend to 1.5°C on the lower end. Both rows assume a 70 percent probability that climate sensitivity is within the "likely" range, rounding up the IPCC's 66 percent number for its definition of "likely." The final row then splits the difference between 66 percent ("likely") and 90 percent ("very likely") to put a probability of 78 percent of being between 1.5 and 4.5°C and a probability of 11 percent of climate sensitivity being above 4.5°C. This works out to a probability of 3 percent that climate sensitivity is above 6°C, which is conservatively low by almost any standards. The final row is what we present in the main text, with numbers further rounded for simplicity.

Page 55—**heavy**: See "fat tail" on page 52.

Page 55—**the median**: Note that we are using the median climate sensitivity of 2.6°C here to calculate temperature increase. Using the more conventional mean climate sensitivity of 3°C would translate into a (mean) temperature increase of 4.0°C based on concentrations reaching 700 ppm (rather than the median figure of 3.4°C presented in the main text).

Page 55—**Black Swan**: Taleb, *Black Swan*.

Page 55—**unknown unknowns**: Donald Rumsfeld popularized the term in the context of the U.S. invasion of Iraq, drawing the analogy at more than one occasion. The first mention was at a Pentagon news conference on February 12, 2002: "Reports that say that something hasn't happened are always interesting to me, because as we know, there are known knowns; there are things we know we know. We also know there are known unknowns; that is to say we know there are some things we do not know. But there are also unknown unknowns—the ones we don't know we don't know. And if one looks throughout the history of our country and other free countries, it is the latter category that tend to be the difficult ones" (Morris, "Certainty of Donald Rumsfeld"). Rumsfeld later echoed the sentiment at least once more, at a NATO press conference on June 6, 2002 (Rumsfeld, "Press Conference").

Economists typically credit Chicago economist Frank Knight for coming up with the idea (Knight, "Risk, Uncertainty, and Profit"). He made the technical distinction between "risk" and "uncertainty." (Note that Knightian "risk" is different from what the average person—including the average scientist—calls "risk." Any layman's "existential risk," including the way we use it in the text, is much closer to Knightian "uncertainty" than Knightian "risk.") Richard Zeckhauser has added a third category: "ignorance." Risk deals with known distributions. Uncertainty is not knowing which distribution to pick. Ignorance is when it's unclear there even is a distribution. See Zeckhauser, "Unknown and Unknowable," and a subsequent reaction: Summers, "Comments."

Page 56—**bad global warming feedbacks**: Walter et al., "Methane Bubbling," attempts to measure methane emissions from thaw lakes in Siberia, estimating that methane emissions from northern wetlands is 10–60 percent higher than previously thought. They find that the largest portion of the methane released comes from the thawing permafrost around lake edges. This process is thought to be a critical one in previous times of climatic change. "Climate Science: Vast Costs of Arctic Change" estimates the total cost to society of methane released from thawing Siberian permafrost to be on the scale of $60 trillion.

Page 56—**Melting of Greenland**: The Greenland ice sheet has a sea level equivalence of 7.36 m (24 feet), and full melting of the Antarctic ice sheet would mean a 58.3 m (191 feet) sea-level rise (see chapter 4, "Observations: Cryosphere," in Working Group I of the *IPCC Fifth Assessment Report*). Full melting of the West Antarctic ice sheet by itself would lead to about 3.3 meters (11 feet) of sea-level rise (Bamber et al., "Potential Sea-Level Rise"). See "centuries of sea-level rise" on page 9 in chapter 1 for more on the irreversibility of it melting.

The *IPCC Fifth Assessment Report* found that the Greenland ice sheet has contributed on average 0.59 mm per year to sea-level rise from 2002 to 2011, while the Antarctica contribution is likely 0.4 mm per year for the same period. Both of these contribution rates have more than quadrupled from the average for 1992 to 2001. The observed global mean sea-level rise for the 1993 to 2010 period was 3.2 mm per year. The IPCC's estimate for total sea-level rise under the worst-case scenario is 0.53 to 0.97 m (1.7 to 3.2 feet). The only situation they believe could increase sea level by 2100 significantly above this likely range would be if marine-based sections of the Antarctic ice sheet collapsed (see chapter 13, "Sea Level Change" in Working Group I of the *IPCC Fifth Assessment Report*).

Page 57—**DICE model**: See the "DICE" entry on page 36 in chapter 2.

Page 57—**$2 per ton**: Nordhaus derives a number of $5 per ton of *carbon* for 1990 to 1999 (Nordhaus, "Optimal Transition Path"). We convert this figure to dollars per ton of *carbon dioxide* and into 2014 dollars using the GDP deflator to arrive at $2 per ton of carbon dioxide.

Page 57—**Nordhaus's preferred "optimal" estimate**: Nordhaus, "Estimates of the Social Cost of Carbon," presents a price of $18.6 per ton of carbon dioxide emitted in 2015 (in 2005 dollars). Converted into 2014 dollars, the figure is around $20 per ton. The paper presents both what Nordhaus considers the "optimal" path and various other scenarios, including one to keep global average temperature increases below 2°C. Note that this $20 estimate is significantly higher than his "optimal" path derived only four years prior. Then the optimal figure for 2015 was $12 (Nordhaus, "Economic Aspects"). Note also that the $20 is lower than both Nordhaus's set of "illustrative carbon prices needed for a 2½°C temperature limit" (figure 33 in

Nordhaus, *Climate Casino*) and the "central" estimate presented in the first table of the "Technical Update of the Social Cost of Carbon for Regulatory Impact Analysis under Executive Order 12866" for a ton of carbon dioxide emitted in 2015. The former is $25 for a ton emitted in 2015. The latter is close to $40 per ton, using an average of three models and a discount rate of 3 percent. Nordhaus's own preferred discount rate is around 4.2 percent. He shows how the difference in discount rates explains most of the difference between the $40 and his own $20 estimate.

Page 58—**around $40**: See "possibly much more" on page 23 in chapter 1.

Page 59—**more equable and better climates**: The full quote: "By the increasing percentage of [carbon dioxide] in the atmosphere, we may hope to enjoy ages with more equable and better climates, especially with regards to the colder regions of the earth, ages when the earth will bring forth much more abundant crops than at present, for the benefit of rapidly propagating mankind" (Arrhenius, *Worlds in the Making*, 63).

The general spirit of the importance of and opportunities in adapting to warmer climates is best represented in Kahn's *Climatopolis*. There are surely costs, Kahn argues, but coping mechanisms create their own opportunities, especially for highly efficient cities.

Page 59—**playing catch-up**: See "$2 per ton" and "Nordhaus's preferred "optimal" estimate" on page 57 for a discussion of the evolution of Nordhaus's DICE estimates. See "possibly much more" on page 23 in chapter 1 for a discussion of the U.S. government's figures.

Page 60—**started by one person**: Bill Nordhaus created DICE. Richard Tol developed FUND, which is now largely maintained by David Anthoff: http://www.fund-model.org/. Chris Hope was the driving force behind PAGE: http://climatecolab.org/resources/-/wiki/Main/PAGE.

Page 60—**massive data operations**: The underlying global circulation models used by climate scientists and feeding into the IPCC reports are indeed computationally complex. However, integrated assessment models then rely on much-simplified output, in DICE's case on the Model for the Assessment of Greenhouse Gas Induced Climate Change (MAGICC), which in turn is a much-simplified version of underlying climate models. DICE itself is freely available on Bill Nordhaus's website and even runs in Excel: http://www.econ.yale.edu/~nordhaus/.

Page 61—**Lots are missing**: See, for example, Howard, "Omitted Damages." Van den Bergh and Botzen, "Lower Bound," similarly present climate change effects that are inadequately captured by models like DICE. Most of these effects would increase estimates of the social cost of carbon. Some may also decrease it. (See "possibly much more" on page 23 in chapter 1.)

Page 61—**quadratic extrapolations**: DICE uses an inverse quadratic loss function linked to temperature (T), where loss is defined as equal to $1/[1+a\,T+b\,T^2]$.

Page 62—**as far out as 6°C**: In fact, Nordhaus, *Climate Casino*, cuts off the graph at 5°C (9°F), implying that any damages due to temperature changes beyond that level are much too uncertain (or perhaps rare) to contemplate.

Page 63—**damages affect output growth** *rates*: See Pindyck, "Climate Change Policy," and Heal and Park, "Feeling the Heat," who link temperature to labor productivity via human physiology. They find high temperatures decrease productivity in already hot—and often poor—countries, while higher-than-average temperatures increase productivity by similar amounts in cool—and typically rich—countries.

Moyer et al., "Climate Impacts on Economic Growth," similarly show large impacts on the Social Cost of Carbon estimate of changing the climate impact from output levels to productivity: "even a modest impact of this type increases SCC estimates by many orders of magnitude."

Page 65—**damages are additive**: See Weitzman, "Damages Function." For a complementary take—focusing on the idea of "relative prices"—see Sterner and Persson, "Even Sterner Review." The fundamental distinction between multiplicative versus additive damage functions rests on questions of substitutability. The (implicit) assumption for multiplicative damages is unit substitutability between economic sectors and environmental amenities within the utility function. Additive damages assume less (to no) substitutability across these sectors in the utility function.

Page 68—**likely underestimate**: See "possibly much more" on page 23 in chapter 1.

Page 68—**discount whichever number**: Many a book and article has been written on the topic. Gollier, *Pricing the Planet's Future*, ranks among the best general introductions.

Page 68—**is worth more**: In fact, having one dollar today is typically worth a lot more than having it tomorrow. Whereas the same one-day difference a hundred years from now is barely noticeable. From today's perspective, a hundred years plus one day is pretty much the same as a hundred years. Quite naturally, humans tend to discount the first day more heavily than that one day a hundred years from now. The technical term for this particular phenomenon is "hyperbolic discounting," most prominently introduced to economics in Laibson, "Golden Eggs."

Page *69*—**2 percent a year**: "10-Year Treasury Inflation-Indexed Security, Constant Maturity."

Page *69*—**criticized for that low choice**: Weitzman, "A Review," argues that "the *Stern Review* may well be right for the wrong reasons," the low discount rate being one of the wrong reasons.

Page *69*—**decline over time**: See Weitzman, "Gamma Discounting," for the declining discount rate numbers mentioned in the text. For a later consensus view around the logic behind declining discount rates, not necessarily the specific numbers, see Arrow et al., "Determining Benefits and Costs," and Cropper et al., "Declining Discount Rates." France and the United Kingdom, for example, use declining discount rates, but they do not agree on the exact rate: France's starts at 4 percent and declines to a bit over 2 percent for numbers 300 years in the future; the UK's starts at 3.5 percent and declines to 1 percent after 300 years.

For an application that reconciles some important technical differences in the application of the basic logic, see Gollier and Weitzman, "Distant Future." It concludes that "The long run discount rate declines over time toward its lowest possible value."

To see the reason behind this declining rate, consider the following thought experiment: Assume we don't know whether the true discount rate for damages a hundred years from now should be 1 percent or 7 percent. The former is on the lower end of rates for U.S. Treasury bills, which come as close to a risk-free investment as possible. The latter comes from the obscure but all-important "Circular A-94," which the powerful U.S. government's Office of Management and Budget suggests as the base-case analysis for all government investment and regulatory decisions (OMB, "Circular No. A-94 Revised"). Note that the 7 percent rate is not a risk-free rate in any sense of that word. In fact, it deliberately deals with risky investment decisions. The big question there is whether the rate for riskier investments ought to go up or down, something discussed in more detail in the text itself.

OMB's other, and more appropriate, rate for something as far out as a hundred years is 3 percent. That's also the government's base case for the $40 social cost of carbon. But for argument's sake, let's use the 7 percent figure for now. It's certainly an upper bound of sorts. Hardly anyone would sensibly argue for a higher discount rate. There's a good reason why: $100 a hundred years from now, discounted at 7 percent is worth 9 cents today. Invest less than a dime today at a rate of return of 7 percent, and expect to get $100 a century hence. For an investor, that's not bad. For discounting climate damages a hundred years out, it makes them almost worthless today. That, of course, is the exact line of reasoning some use to argue why climate damages don't matter all that much. Why worry about costs of global warming in a century, if all it takes is setting aside relatively little money today to cover the damages? All that holds true at 7 percent. But $100 a hundred years from now, discounted at 1 percent, is worth $37 today. That's quite a bit more.

Let's split the difference and use a 4 percent discount rate, halfway between 1 and 7 percent: now $100 a hundred years from now is worth $1.8 today. That's much, much closer to 9 cents from the 7 percent discount rate than the $37 from a 1 percent rate. But that's only one way of "splitting the difference." What if we just didn't know whether the rate should be 1 percent or 7 percent?

Put the chance of either rate at 50–50. That's a 50 percent probability that the correct number should be 9 cents, and a 50 percent probability that it should be $37. On average, that's roughly $18. That average of the discounted numbers is much higher than the number using the average discount rate of 4 percent = (7 percent + 1 percent)/2. In fact, in our example, the difference is a factor of ten: $18 versus $1.80. And the difference increases the further out you go.

Lastly, for a different argument for declining discount rates, see Heal and Millner, "Agreeing to Disagree." They suggest that the choice of discount rate is an "ethical primitive" to arrive at the same conclusion of declining discount rates.

Page 70—**Black-Litterman Global Asset Allocation Model**: Black and Litterman, "Global Portfolio Optimization."

Page 71—**stark implications**: "If climate risk dominates economic growth risk because there are enough potential scenarios with catastrophic damages, then the appropriate discount rate for emissions investments is lower tha[n] the risk-free rate and the current price of carbon dioxide emissions should be higher. In those scenarios, the 'beta' of climate risk is a large negative number and emissions mitigation investments provide insurance benefits. If, on the other hand, growth risk is always dominant because catastrophic damages are essentially impossible and minor climate damages are more likely to occur when growth is strong, times are good, and marginal utility is low, then the 'beta' of climate risk is positive, the discount rate should be higher than the risk-free rate, and the price of carbon dioxide emissions should be lower" (Litterman, "Right Price"). For earlier use of "*beta*" in the climate context, see Sandsmark and Vennemo, "Portfolio Approach," for an argument for a negative *beta* of mitigation investments. Gollier, "Evaluation of Long-Dated Investments," makes the case for a positive *beta*.

Page 72—**equity premium puzzle**: For an overview, see Mehra, "Equity Premium Puzzle."

Page 72—**reverses the equity premium puzzle**: For a technical exploration of this argument, see Weitzman, "Subjective Expectations," or Barro, "Rare Disasters." See Mehra, "Equity Premium Puzzle," for alternative explanations of the equity premium puzzle and a survey of the ongoing debate.

Page 72—**"black" days**: *Black Monday* on October 19, 1987, saw the Dow drop 22 percent; *Black Tuesday* on October 29, 1929, marked the beginning of the Great Depression; *Black Wednesday* on September 16, 1992, earned George Soros a billion pounds betting against the Bank of England; *Black Thursday* on October 24, 1929, saw Wall Street lose over 10 percent almost at the opening bell (recall *Black Tuesday* just above for what happened next); *Black Friday* on September 24, 1869, saw markets crash after a failed attempt to corner the gold market. None of it should be confused with the *Black Week* beginning Monday, October 6, 2008, when the Dow fell 18 percent by Friday. The front-page articles of the *Wall Street Journal* after each of these events make for interesting, contemporaneous reading: For the reaction to what we now know as "Black Monday," see Metz et al., "Crash of '87." After Black Tuesday and Thursday, the two days that are seen as the beginning of the Great Depression, the WSJ seems surprisingly nonchalant. "Pressure Continues: Stocks Sink Lower under Record Volume of Liquidation," (published October 30, 1929) recognizes the huge drop in stock prices from the day before, but also states that "industrial activity is on a large scale and sound basis with no real indications of a depression in prospect," and projects that "after the initial shock has worn off the decline will prove beneficial in many ways by releasing funds from market to industry." "Demoralized Trading: Stocks Break on Record Volume—Banking Support Starts Rally" (published October 25, 1929), somewhat more awed by the situation, opens with the statement, "Yesterday's market was in many respects the most extraordinary in the history of the Stock Exchange." However, the article also ends with a projection that the market would turn around soon. Zweig, "What History Tells Us," looks at the preceding "Black Week" in comparison to and in the context of the "Great Crash." For the front-page article of London's *Financial Times* on the day after Black Wednesday, see Stephens, "Major Puts ERM Membership on Indefinite Hold."

Page 73—**drawing the link**: Litterman, "Right Price."

Page 74—**won't happen tomorrow**: We have a much better idea of warming in the short and medium term: For the next two decades (2016 to 2035), the Summary for Policymakers in Working Group I of the *IPCC Fifth Assessment Report* finds, with "medium confidence," a "likely" additional warming of between 0.3 and 0.7°C (0.5 and 1.3°F) relative to the past two decades (1986–2005).

For the final two decades of this century, the predictions diverge dramatically. Depending on which scenario one chooses, average global warming relative to the past two decades could be anywhere from 0.3–1.7°C, to 2.6–4.8°C (0.5–3.1°F, to 4.7–8.6°F), an enormous range with dramatically different consequences. And those are just the likely ranges. See, for example, "0.3 to 1 meters" on page 5 of chapter 1 for the implications for sea-level rise.

Note that all these estimates, including for sea-level rise, are relative to the two decades ending in 2005. 4.8°C (8.6°F) of additional warming relative to "today" would mean total warming of 5.5°C (9.9°F) from preindustrial levels.

Page 74—**the longer it will take**: See Roe and Bauman, "Climate Sensitivity," for this point. They employ a standard willingness-to-pay framework to conclude that fat tails may not be that costly. (For a contrasting conclusion by the same [lead] author, see Roe, "Costing the Earth.")

Page 77—**European Union**: See Ellerman, Convery, and de Perthuis's *Pricing Carbon* for an early yet comprehensive survey of the EU's emissions trading system.

Page 77—**sole exception is Sweden**: See Hammar, Sterner, and Åkerfeldt, "Sweden's CO_2 Tax," and Johansson, "Economic Instruments in Practice."

Page 77—**decision criterion**: For a recent elaboration on the point around alternative decision criteria, see Heal and Millner, "Uncertainty and Decision." Also see Millner, Dietz, and Heal, "Scientific Ambiguity and Climate Policy."

Page 78—**ethical component**: For a climate scientist making the strong moral case, see Roe, "Costing the Earth." For a moral philosopher making the strong case for economists to engage on the moral dimension, see Sandel, "Market Reasoning as Moral Reasoning."

CHAPTER 4. WILLFUL BLINDNESS

Page 80—**U.S. Supreme Court**: *Global-Tech Appliances, Inc., et al. v. SEB S.A.*

Page 81—**colloquial interpretation**: For a popular take on "willful blindness"—with some brief cameos by climate change—see Heffernan, *Willful Blindness*.

Page 81—**tax or cap carbon**: See our discussion of taxes versus cap and trade in chapter 1.

Page 81—**close to zero**: See "$500 billion per year" on page 22 in chapter 1.

Page 81—**around $40**: See "possibly much more" on page 23 in chapter 1.

Page 83—**value of a statistical life**: For two good recent surveys, see Ashenfelter, "Measuring the Value of a Statistical Life," and Viscusi and Aldy, "Value of a Statistical Life."

Page 83—**one percent chance**: For the full quotation and the argument for why this is a false equivalency, see Sunstein, *Worst-Case Scenarios*. Whatever damage the certain event would cause, having it occur with a probability of 1 percent would imply that its damage estimates need to be divided by a hundred to have a sensible metric of comparison.

Page 84—**Worst-Case Scenarios**: For a discussion of worst-case scenarios, start with Sunstein, *Worst-Case Scenarios*. Another oft-cited treatise on the subject is Posner, *Catastrophe: Risk and Response*. See Parson, "The Big One," for a comprehensive summary and critique, as well as further important elaborations. For an attempt at a comprehensive classification that goes beyond our list of eight potential existential risks, see Bostrom and Ćirković, *Global Catastrophic Risks*. For a more technical discussion, with a "can-do" attitude, see Garrick, *Quantifying and Controlling Catastrophic Risks*.

Page 85—**Their verdict**: For a summary, see Parson, "The Big One."

Page 86—**underestimating the likelihood**: See "1-in-1,000-year event" on page 1 in chapter 1.

Page 86—**$2 to 3 billion**: See "$2 or 3 billion" on page 1 in chapter 1.

Page 87—**guiding principle**: See, among many others, Revesz and Livermore, *Retaking Rationality*.

Page 88—**nuclear terrorism is worse**: Bostrom and Ćirković, *Global Catastrophic Risks*, puts the probability of catastrophic nuclear terrorism at 1 to 5 percent. By contrast—and on the extreme end of educated guesses—Allison, *Nuclear Terrorism*, p. 15, states that "a nuclear terrorist attack on America in the decade ahead is more likely than not." Silver, "Crunching the Risk Numbers," converts this to a 5 percent chance per year of such a catastrophe striking this coming decade.

Page 90—**Contrast the historical precedent**: This logic and some language in this paragraph is taken from Weitzman, "Modeling and Interpreting the Economics."

CHAPTER 5. BAILING OUT THE PLANET

Page 92—**Bailing Out the Planet**: The technical term for the type of geoengineering we discuss here is "solar-radiation" or "shortwave radiation management," both abbreviated by "SRM." That stands in contrast to "direct carbon removal" (DCR) or "carbon dioxide removal" (CDR). (For the latter, see "comes under various guises" on page 107 in chapter 5 as well as the "Bathtub" entry on page 30 in chapter 2.)

Despite the science still being in its infancy, geoengineering is slowly but surely entering public conversations. For one of the best such public documents, see Keith, *A Case for Climate Engineering*. For one of the most accessible, see Goodell, *How to Cool the Planet*. For one of the strongest, well-argued rejoinders, see Hamilton, *Earthmasters*. For our own earlier take, see Wagner and Weitzman, "Playing God."

Page 92—**make development sustainable**: United Nations, *Our Common Future*, commonly known as the "Brundtland Report."

Page 92—**the Earth's atmosphere**: Global average temperatures increased 0.45°C from the average measured between 1861 and 1880 to the average measured between 1980 and 1989 (chapter 7, "Observed Climate Variations and Change," of the *IPCC First Assessment Report*).

Page 93—**displaced over 200,000**: McCormick, Thomason, and Trepte, "Atmospheric Effects."

Page 93—**tons of sulfur dioxide**: Estimates range from 17 million tons of sulfur dioxide (Self et al., "Atmospheric Impact") to above 20 million (Bluth et al., "Global Tracking"). Note that the metric here is sulfur dioxide. For the weight of sulfur alone, divide these estimates by two.

Page 93—**tons of carbon dioxide**: We calculated these numbers using parts per million (ppm) levels from Keeling et al., *Exchanges of Atmospheric* CO_2, and used the conversion rate of 2.13 billion tons of carbon per ppm from the Carbon Dioxide Information Analysis Center. ("Conversion Tables"). The generally accepted preindustrial level of carbon dioxide in the atmosphere is 280 ppm, or 2.19 trillion tons of carbon dioxide. In 1990, the measured carbon dioxide concentration was 355 ppm, equivalent to 2.77 trillion tons. That is 585 billion tons above the preindustrial level. By now, average carbon dioxide levels are 400 ppm, or around 3.1 trillion tons carbon dioxide. Subtracting, we get 940 billion tons above preindustrial levels.

Page 93—**still pointing up**: See "2 ppm" on page 22 in chapter 1.

Page 94—**5,000 times:** Little Boy was about 20,000 as powerful as traditional bombs at the time (White House Press Release on August 6, 1945). The power-to-mass ratio of Little Boy compared to one ton of conventional explosives averages out to about 4,500. The bomb killed over 80,000 people, even though only 1.38 percent of the bomb's nuclear core fissioned during the explosion (Schlosser, *Command and Control*). The most powerful atomic bomb deployed was Ivy King, with a power-to-mass ratio of roughly 128,000—a TNT-equivalent power of 500,000 tons, and weighing 3.9 tons ("Operation Ivy").

Page 94—**Titan II missile**: Eric Schlosser's *Command and Control* provides a terrific journalistic account of the evolution of the nuclear bomb and the ways the world has tried—and in some cases, almost failed—to control it.

Page 94—**a million to one**: Keith, *A Case for Climate Engineering*, p. 67, compares total tons of carbon dioxide to the effect of pumping one million tons of sulfur into the stratosphere every year. The resulting leverage ratio is near a million to one.

Page 95—**2 to 3 percent**: Mount Pinatubo was the best-studied volcanic eruption, with dozens of papers estimating total solar radiation impacts alone. Most present the results in Watts per square meter. Direct solar radiation decreased by as much as 25–30 percent as a direct result of the volcanic eruption. Averaged over the first 10 months, "monthly-mean clear-sky total solar irradiance at Mauna Loa, Hawaii, decreased by as much as 5 percent and averaged . . . 2.7 percent" (Dutton and Christy, "Solar Radiative Forcing"). Models later found similar results (Stenchikov et al., "Radiative Forcing"). The NASA Earth Observatory confirms these numbers: "While overall solar radiation was reduced by less than five percent, data showed a reduction of direct radiation by as much as 30 percent."

Page 95—**more acidic**: Caldeira and Wickett, "Oceanography." See also "Ocean acidification" on page 42 in chapter 2.

Page 95—**created more**: Incidentally, making oceans (or other ecosystems) even more acidic does not appear to be one of these problems. Carbon dioxide turns oceans more acidic. So does sulfur—in form of sulfuric acid—after it washes out of the atmosphere. However, acidification from carbon dioxide in oceans is 100 times as strong as any effects of sulfur deposition from Mount Pinatubo–style geoengineering, at least via the damage pathway of acid rain. Kravitz et al., "Sulfuric Acid Deposition," argues that "the additional sulfate deposition that would result from geoengineering will not be sufficient to negatively impact most ecosystems, even under the assumption that all deposited sulfate will be in the form of sulfuric acid."

Page 95—**low levels of stratospheric ozone**: McCormick, Thomason, and Trepte, "Atmospheric Effects," estimate that the eruption of Mount Pinatubo could have been responsible for a decrease of columnar ozone above the equator by 6–8 percent. Self et al., "Atmospheric Impact," show how the depletion of ozone after the eruption was higher than ever before recorded. Heckendorn et al., "Impact of Geoengineering Aerosols," use the ozone depletion associated with the Pinatubo eruption as a case study for their conclusion that geoengineering with tiny sulfur-based particles would result in a "significant depletion of the ozone layer."

The direct effects of Mount Pinatubo, however, should not be conflated with the overall effects of any future geoengineering efforts, as global temperature increases themselves may accelerate ozone destruction, an effect possibly reversed or prevented by geoengineering. See, for example, Kirk-Davidoff et al., "Effect of Climate Change," and Keith, "Photophoretic Levitation."

Page 95—**global dry spell**: Trenberth and Dai, "Effects of Mount Pinatubo." See also Jones, Sparks, and Valdes, "Supervolcanic Ash Blankets."

Page 96—**where should we stop**: Alan Robock cites this question of who controls the thermostat, among 19 other practical problems, as a reason geoengineering might be more trouble than it's worth. Robock, "20 Reasons." Another set of questions with no easy answers concerns the morality of "hacking the planet." Stephen Gardiner outlines a moral argument against geoengineering, and particularly against the idea that researching geoengineering is a "lesser evil" when compared to catastrophic climate change, in "Arming the Future."

Page 97—**subsidized worldwide**: See "$500 billion per year" on page 22 in chapter 1.

Page 98—**roughly a ton**: There are plenty of other direct and indirect effects of aviation. For comprehensive surveys, see Dorbian, Wolfe, and Waitz, "Climate and Air Quality Benefits," and Barrett, Britter, and Waitz, "Global Mortality."

Page 98—**$40 worth of damages**: See "possibly much more" on page 23 in chapter 1.

Page 98—**transatlantic flights**: A roundtrip flight from New York City to Europe has a carbon footprint of 2–3 tons per passenger. Rosenthal, "Biggest Carbon Sin."

Page 98—**30 million**; **three billion**: Numbers for 2012 from International Civil Aviation Organization (ICAO)'s "The World of Civil Aviation: Facts and Figures."

Page 99—**Voluntary coordination**: The late Ronald Coase, the originator of the idea that—under certain strong conditions—coordination among individuals ("Coasian bargaining") can arrive at the socially optimal solution, would have agreed. See Glaeser, Johnson, and Shleifer, "Coase vs. the Coasians." One major stumbling block is the presence of large transaction costs for a negotiation among so many actors. Coase is widely credited with introducing that very idea of transaction costs to economics, which he used to explain the role of firms (Coase, "The Nature of the Firm"). The seminal article that introduced what would later be known as "Coasian bargaining" made it clear that well-defined property rights and low transaction costs were a precondition for its success (Coase, "The Problem of Social Cost").

Page 100—**too cheap to ignore**: Royal Society, "Geoengineering the Climate," estimates the cost of cooling the planet through tiny particles injected into the stratosphere to be \$0.2 billion/year/W/m^2. This is compared to an estimated \$200 billion/year/W/m^2 for reducing carbon dioxide in the first place. Schelling, "Economic Diplomacy of Geoengineering," is among the first economists to make this point. Barrett, "Incredible Economics of Geoengineering," may be the most prominent. Keith, "Geoengineering the Climate," and Royal Society, "Geoengineering the Climate," are the most authoritative. Goes, Tuana, and Keller, "Economics (or Lack Thereof)," and Klepper and Rickels, "Real Economics of Climate Engineering," have since added important caveats. McClellan, Keith, and Apt, "Cost Analysis," has recently added further perspectives. Finally, Bickel and Agrawal, "Reexamining the Economics," extends the work of Goes et al. and changes some assumptions to find that geoengineering will pass a benefit-cost test under more scenarios.

Page 102—**Asilomar Process**: Berg, "Asilomar and Recombinant DNA." For the original Asilomar statement, see Berg et al., "Summary Statement."

Page 102—**last of these headlines**: Giles, "Hacking the Planet."

Page 102—**Asilomar 2.0.**: Environmental Defense Fund was one of the cosponsors of the event.

Page 103—**firsthand account**: Schneider, *Science as a Contact Sport*.

Page 103—**The final statement**: "Asilomar Conference Recommendations," prepared by the Asilomar Scientific Organizing Committee.

Page 103—**Mount Pinatubo–style remedies**: Geoengineering has garnered a significant amount of attention since the 2006 publication of Crutzen, "Albedo Enhancement," which broke a long-standing taboo of sorts. An informal survey of the 77 articles on "geoengineering" in the journal *Climatic Change* shows that 19 had been published in the 18 years from 1977 to 2005. Between 2006 and 2013, the number was 58. The year 2013 alone saw the publication of 23 articles on geoengineering, and that's just in this one journal.

Page 104—**trade-off**: Many economists call this "moral hazard," which David Keith may have been the first to use in the geoengineering context (Keith, "Geoengineering the Climate"). The label has stuck, even though Scott Barrett has argued convincingly that it isn't technically true. Moral hazard refers to incentive problems between two parties. Driving faster because of wearing a seat belt is simply lack of self-control. Similarly, Keith, *A Case for Climate Engineering*, p. 139, describes some of the ensuing debate as "moral confusion, not moral hazard."

Page 105—**vast majority of Americans**: Tony Leiserowitz presented these results at the Asilomar Conference in March 2010. He has not asked the question since.

Page 105—**Painting roofs white**: See Menon et al., "Radiative Forcing." The *Royal So*ciety's "Geoengineering the Climate" describes roof whitening as one of the "least effective and most expensive methods considered." The report estimates roof whitening to be 10,000 times more expensive per W/m^2 reduction in radiative forcing than Mount Pinatubo–style geoengineering.

Page 105—**vicious circles**: Curry, Schramm, and Ebert, "Sea Ice-Albedo."

Page 106—**urban areas elsewhere**: Oleson, Bonan, Feddema. "Effects of White Roofs," finds that painting roofs white in urban setting could reduce the urban heat island effect by a third, reducing daily maximum temperature by 0.6°C (1.1°F).

Page 106—**making things worse**: Jacobson and Ten Hoeve, "Urban Surfaces and White Roofs."

Page 106—**a tenth of the impact**: Menon et al., "Radiative Forcing," estimates the carbon dioxide offset of painting all roofs and pavements in urban areas white to be around 57 billion tons. Mount Pinatubo's eruption offset 585 billion tons of carbon dioxide.

Page 106—**need for air-conditioning**: "Cool Roof Fact Sheet."

Page 106—**some serious proposals**: Several recent studies look at the effects. See, for example, Latham et al., "Marine Cloud Brightening," Jones, Haywood, and Boucher, "Geoengineering Marine Stratocumulus Clouds," Latham et al., "Global Temperature Stabilization," Salter, Sortino, and Latham, "Sea-Going Hardware."

Page 107—**Indian monsoon**: Keith, *A Case for Climate Engineering*, p. 57–60, describes discussion of the Indian monsoon as among the most polarizing regional effects of geoengineering in the context of injecting sulfates into the stratosphere. Compare, for example, Robock, Oman, and Stenchikov, "Regional Climate Responses," with Pongratz et al., "Crop Yields." The former points to geoengineering as potentially "reducing precipitation to the food supply for billions of people." The latter points to geoengineering as potentially increasing crop yields in India.

Page 107—**comes under various guises**: See the Royal Society's "Geoengineering the Climate" for a comprehensive overview of geoengineering methods. All come with their own caveats and exceptions. The efficacy of some is under serious dispute. One recent study on biochar, for example, shows that it might not work as well as previously thought. Jaffé et al., "Global Charcoal Mobilization," finds that the carbon is not all captured, but rather a large portion dissolves and is released into rivers and oceans. Multiple other studies show a range of estimates for the "mean residence time" of biochar, ranging from 8.3 years (Nguyen et al., "Long-term Black Carbon"), to 3,624 years (Major et al., "Fate of Soil-Applied Black *Carbon*). Gurwick et al., "Systematic Review of Biochar Research," reviewed over 300 peer-reviewed articles on biochar and concluded that it's impossible to conclude very much at all based on the limited and wide range of data currently available.

Page 108—**Ocean fertilization**: Many scientists think that ocean fertilization is an inefficient route to carbon removal, and implementation on a large scale would likely be ineffective and disruptive to the marine ecosystem. Strong et al., "Ocean Fertilization."

Page 110—**0.8°C**: See "warmed by 0.8°C (1.4°F)" on page 13 in chapter 1.

Page 110—**By 2100**: The Summary for Policymakers of the *IPCC Fifth Assessment Report*'s Working Group I gives 3–5°C as the approximate range of temperature change by 2100 for the RCP8.5 scenario. The U.S. EPA estimates temperature changes up to 11.5°F by 2100 ("Future Climate Change").

Page 110—**serious problems**: See "Mark Lynas" and "HELIX" on page 14 in chapter 1.

Page 110—**A sudden jump**: The technical term is the "termination effect." Jones et al., "Impact of Abrupt Suspension," used 11 different climate models to examine this effect. They found substantial agreement among the models that sudden termination of long-term geoengineering would induce rapid increase in mean global temperature and precipitation, as well as a rapid decrease in sea ice cover. Matthews and Caldeira, "Transient Climate–Carbon Simulations," estimated that warming rates after a sudden termination of geoengineering could be up to 20 times those today.

Page 110—**national security threat**: See Gwynne Dyer's *Climate Wars* for one of the most vivid takes. The "Quadrennial Defense Review Report" from the U.S. Department of Defense declared, "climate change and energy are two key issues that will play a significant role in shaping the future security environment." Hsiang, Meng, and Cane, "Civil Conflicts," shows just that in the historical record, demonstrating that El Niño / Southern Oscillation may have played a role in a fifth of all civil conflicts since 1950. Hsiang, Burke, and Miguel, "Influence of Climate" reviews 60 studies on climate and human conflict and finds a substantial causal link between the two.

Page 111—**means less rainfall**: For a good survey of this phenomenon, see Ricke, Morgan, and Allen, "Regional Climate Response." Self et al., "Atmospheric Impact," note that the Mississippi floods could be attributable to the Mount Pinatubo eruption. See also Christensen and Christensen, "Climate Modelling." For more on general attribution science around climate change rather than geoengineering, see "attribution science" on page 4 in chapter 1.

Page 111—**attribution science**: See "attribution science" on page 4 in chapter 1.

Page 112—**Commission is worse**: See Samuelson and Zeckhauser, "Status Quo Bias," and Kahneman, Knetsch, and Thaler, "Anomalies."

For a closely related concept, the "doctrine of double effect," see Thomson, "The Trolley Problem." Also see "errors of omission become as bad" on page 125.

Page 112—**best-studied**: McCormick, Thomason, and Trepte, "Atmospheric Effects."

Page 112—**experiment with the atmosphere**: See Robock, "Is Geoengineering Research Ethical?," for an ethical argument against geoengineering research outside the lab. There is indeed a broader set of issues, sometimes referred to as the "Collingridge dilemma": we can't know about the impacts of a technology until we have it; and once we have it, basic forces push us toward using it (Collingridge, *The Social Control of Technology*).

Page 113—**since the 1800s**: See the "Climate Science" entry on page 35 in chapter 2.

Page 113—**term "global warming"**: See "Wally Broecker" on page 49 in chapter 3.

Page 114—**other similar efforts**: Asilomar 2.0 is only one example. Another is the Solar Radiation Management Governance Initiative, convened by the British Royal Society, the Academy of Sciences for the Developing World, and the Environmental Defense Fund. By some assessments, Asilomar itself was only an extension of the "Oxford Principles" on geoengineering. These principles were submitted in 2009 to the UK House of Commons Science and Technology Select Committee's report, "The Regulation of Geoengineering," and subsequently endorsed by both the committee and the UK government. The authors of the principles also wrote a paper explaining their function and proposing a method for their implementation. (See Rayner et al., "The Oxford Principles.")

Page 114—**End the Deadlock**: Parson and Keith, "End the Deadlock." This isn't David Keith's first foray into governance issues by far. See http://www.keith.seas.harvard.edu/geo-engineering/.

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Page 120—**possibility of a "Greenfinger"**: Wood, "Re-engineering the Earth." In fact, some might say it has already happened, at least on a tiny scale. In 2012, adversaries of geoengineering and scientists alike were incensed when they discovered that American businessman Russ George had conducted a rogue "experiment" of ocean fertilization, dumping 100 tons of iron sulfate (five times more than any previous fertilization experiment) into the Pacific Ocean in order to spark an enormous plankton growth, which he thought would both suck carbon out of the atmosphere, and aid in the recovery of the local salmon fishery. George's "experiment" was attacked as unscientific, illegitimate, and irresponsible, and George himself was dubbed "the first geo-vigilante" (Specter, "The First Geo-Vigilante"; Fountain, "Rogue Climate Experiment"). It turns out that the fishing village Old Massett of Haida Nation had voted to lend money to the Haida Salmon Restoration Corporation for the project in the hopes of bringing the local salmon fishery back from the brink, and George was brought on as chief scientist only later. It is as of yet unclear if the experiment will help restore the salmon population (Tollefson, "Ocean-Fertilization").

Page 120—**other question marks**: For another take on a future scenario of a geoengineered planet, see Weitzman, "The Geoengineered Planet." For perhaps the most comprehensive take on the science, politics, and ethics—with a strong point of view—see (once again) Keith, *A Case for Climate Engineering*.

Page 120—**Tens of millions more**: From the major East Asian rivers, Brahmaputra and Indus are likely to be most affected by melting Himalayan glaciers, "threatening the food security of an estimated 60 million people." Immerzeel, van Beek, and Bierkens, "Asian Water Towers."

Page 123—**bad health effects**: The potential health impacts of sulfur deposition from geoengineering is an area that has not yet been studied extensively. Initial results from a study conducted by David Keith at Harvard and Sebastian Eastham at MIT indicate that stratospheric injection of tiny particles could cause up to several thousand deaths per year. Another issue, quite separate from the direct health effects of sulfur, is potential sulfur deposition in oceans and other ecosystems. See "created more" on page 95 in chapter 5 on this point.

Page 124—**killing over 3.5 million**: In "Ambient (Outdoor) Air Quality and Health," the World Health Organization estimates that outdoor air pollution from human activities (e.g., transport and power generation) kills 3.7 million people annually. Indoor air pollution kills another 3.3 million for a total of seven million people ("7 Million Premature Deaths Annually Linked to Air Pollution").

Page 124—**Avoiding blame**: Weaver, *Politics of Blame Avoidance*.

Page 125—**errors of omission become as bad**: This thought experiment has a well-grounded foundation in moral philosophy, with no good solution to speak of. It is a matter of degrees. See Parfit, "Five Mistakes in Moral Mathematics." The same question is often presented in the so-called trolley problem. See Michael Sandel's *Justice*, David Edmonds's *Would You Kill the Fat Man?*, and Thomson, "The Trolley Problem."

In *Reasons and Persons* Parfit also identifies another, oft-stated philosophical objection to worrying about the effects of climate change (as well as geoengineering) in the first place: the "non-identity problem." Climate change will alter the course of history as we know it, changing human settlement, migration, and, thus, mating patterns. As a result, future generations will be made up entirely of people who would not have been born without the effects of climate change. How then can we say that future generations will be harmed by climate change (or geoengineering), if the exact same people would not even be alive without climate change (or geoengineering)? Parfit himself, quite rightfully, identifies the "non-identity problem" as something that merits an immediate workaround, and there are several. Perhaps the best for our purposes is that the act itself (climate change or geoengineering) is potentially bad for the future person without making him or her strictly worse off in the non-identity sense of the word of not having been born. Either way, the distinction around errors of commission and omission stands. And in some ways, the issue of errors of commission and omission by various degrees is significantly more difficult to resolve than the fundamental (non-) objection of the "non-identity problem."

Page 126—**The mathematical derivation**: For the technical derivations, see Weitzman, "Voting Architecture." The paper derives the ideal voting rule in terms of Type I and Type II errors. The technical definition of a Type I is the incorrect rejection of a particular hypothesis. Assume that climate change is so bad it requires a geoengineering intervention. Proceed accordingly, only to find out later that geoengineering does more harm than good: an error of commission. Type II errors correspond to errors of omission in this thought experiment: Assume that climate change does not warrant a geoengineering intervention, only to find out later that it was indeed necessary, but now it is too late.

For a critical discussion of this voting architecture and two further analyses of geoengineering governance, see Barrett, "Solar Geoengineering's Brave New World."

CHAPTER 7. WHAT YOU CAN DO

Page 128—**1 in 60 million**: Gelman, Silver and Edlin, "What Is the Probability."

Page 128—**fraction of a penny**: Brennan, *Ethics of Voting*, p. 19, calculates the precise number in this hypothetical example to be $4.77 × 10 to the –2,650th power: approximately zero.

Page 129—**folk theory of voting ethics**: Brennan, *Ethics of Voting*.

Page 130—*But Will the Planet Notice?*: Wagner, *But Will the Planet Notice?* A version of the main arguments appeared as an op-ed in the *New York Times*: Wagner, "Going Green but Getting Nowhere."

Page 131—**if everyone does a little**: Emphasis not needed. David MacKay has italicized these words for us in: MacKay, *Sustainable Energy—without the Hot Air*.

Page 131—**self-perception theory**: Bem, "Self-Perception Theory." Also see Thøgersen and Crompton, "Simple and Painless?" for a comprehensive survey that points to the theories for complementarity from individual to collective action, and then points to the limitations of such a spillover.

Page 132—**bike to work**: See, for example: "Bike City," "Copenhagen: Bike City for More Than a Century," and "Bicycling History," *Cycling Embassy of Denmark*.

Page 132—**environmental decade**: See "Nixon went on to sign" on page 20 in chapter 1, as well as the text around it.

Page 133—**the "crowding-out bias"**: Another version of it is "single-action bias." Columbia's Center for Research on Environmental Decisions' CRED Guide provides an excellent resource on the psychology of climate change (communication) in general, in addition to a good primer on the single-action bias.

Page 133—**poorly studied**: Some research is beginning to investigate the link from individual to collective action and shows a self-reinforcing link, but only in a stated-preference context (Willis and Schor, "Changing a Light Bulb"). This type of research makes economists inherently uncomfortable. Asking people how they will act is one thing. Observing them is quite another.

Page 133—**crowds out virtuous behavior**: Titmuss's *The Gift Relationship* was among the first to hypothesize about this "crowding out" phenomenon from collective to individual action. Frey and Oberholzer-Gee, "Cost of Price Incentives," have revived interest in this work by establishing the theoretical underpinnings. Others have demonstrated its partial empirical validity, most notably perhaps in the context of paying for blood donations (Mellström and Johannesson, "Crowding Out in Blood Donation").

Page 133—**increase their electricity consumption**: The overall effect in terms of decreased emissions is still positive in this one example, as increased electricity use does not entirely offset the decreased pollution from participating in the program in the first place. See Jacobsen, Kotchen, and Vandenbergh, "Behavioral Response."

Page 136—**Sir Richard Branson**: Sir Richard Branson, chairman of Virgin Airlines, speaking at a U.S. State Department Conference on the "Global Impact Economy," on April 26, 2012 ("Interview of Virgin Group Ltd Chairman Sir Richard Branson by The Economist New York Bureau Chief Matthew Bishop").

Page 139—**two "100-year" storms**: See "Irene killed 49" and "Sandy killed 147" on page 2 in chapter 1.

Page 139—**price on carbon**: See "subsidized worldwide" on page 97 in chapter 5.

Page 140—**insurers and re-insurers**: Leurig and Dlugolecki, *Insurer Climate Risk*, offers a word of caution: Smaller insurers, in particular, may well need to be better prepared to weather their own climate risks.

Page 140—**rebuilding properties**: WNYC and ProPublica analyzed federal data and found that over 10,000 homes and business owners will be receiving Small Business Administration disaster loans to rebuild in flood-prone areas (Lewis and Shaw, "After Sandy"). New York has allocated $171 million to the buyout program, out of a $51 billion federal aid package. However, many homeowners are opting to rebuild in flood-prone zones rather than move to a new area (Kaplan, "Homeowners").

Page 141—**breaching typical New York seawalls**: See "three to twenty years" on page 5 in chapter 1.

Page 141—**hundreds of billions of dollars**: The New York Department of Finance's Fiscal Year 2014 Tentative Assessment Roll estimates the value of properties to be $873.7 billion.

Page 142—**stated emissions reductions targets**: See "700 ppm" on page 14 in chapter 1.

Page 142—**global warming exceeding 6°C**: See table 3.1 in chapter 3.

Page 143—**carbon dioxide alone**: See "400 parts per million" on page 10 and "2 ppm" on page 22 in chapter 1.

Page 143—**atmospheric tub**: See "The Bathtub Problem" beginning on page 15 of chapter 1 and the "Bathtub" entry on page 30 in chapter 2.

Page 144—**Bill McKibben**: McKibben, "Global Warming's Terrifying New Math." For additional analysis, see Generation Foundation, "Stranded Carbon Assets." For a good summary, see "A Green Light."

Page 145—**outperforming the market**: Margolis, Elfenbein, and Walsh, "Does It Pay to Be Good," find a small, positive effect. Eccles, Ioannou, and Serafeim, "Corporate Culture of Sustainability," match up "high" with "low" sustainability companies to find a sizeable, positive effect. Conversely, fossil fuel companies seem to have underperformed of late relative to broad market averages (Litterman, "The Other Reason for Divestment"). Investment under uncertainty is an important topic in and of itself. Option value theory applied to decreasing emissions and to coping with and profiting from climate change is clearly an important avenue for further research.

Page 145—**tobacco stocks**: The Australian High Court decision in favor of upholding the Tobacco Plain Packaging Act (2011) in *British American Tobacco Australasia Limited and Ors v. The Commonwealth of Australia*. See "Tobacco Shares Fall on Australian Packaging Rule."

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Page 148—**What We Know**: See whatweknow.aaas.org. The direct quote comes from the American Association for the Advancement of Science (AAAS) Climate Science Panel's background document "What We Know." Also see Melillo, Richmond, and Yohe, "Climate Change Impacts in the United States," and Risky Business Project, *Risky Business*. The latter shows how dealing with climate change is largely a risk management problem.

Page 149—**$40 per ton**: See "possibly much more" on page 23 in chapter 1.

Page 149—*negative* $15: See "$500 billion per year" on page 22 in chapter 1.

Page 149—**0.3 to 1 meters**: See "0.3 to 1 meters" on page 5 in chapter 1.

Page 149—**20 meters**: See "Global average temperatures" on page 10 in chapter 1.

Page 149—**1-in-10 chance**: See Table 3.1 in chapter 3.

Page 150—**cutting the flow**: See "The Bathtub Problem" on page 15 of chapter 1 and the "Bathtub" entry on page 30 in chapter 2.

Page 150—**baked in**: See "decades of warming" and "centuries of sea-level rise" on page 9 in chapter 1.

Page 151—**independent goal**: See Piketty, *Capital*, for perhaps the most comprehensive, contemporary argument.

Page 151—**taxing the rich and filthy**: See Klein, "Capitalism vs. the Climate," for the original quote, as well as Wagner, "Naomi Klein," for a response. Klein, *This Changes Everything*, emphasizes her earlier arguments. The book's subtitle: "Capitalism vs. the Climate."

Bibliography

"7 Million Premature Deaths Annually Linked to Air Pollution." World Health Organization (March 25, 2014). http://www.who.int/mediacentre/news/releases/2014/air-pollution/en/.

"10-Year Treasury Inflation-Indexed Security, Constant Maturity." FRED Economic Data (March 17, 2014). http://research.stlouisfed.org/fred2/series/DFII10/.

Acemoglu, Daron, Philippe Aghion, Leonardo Bursztyn, and David Hemous. "The Environment and Directed Technical Change." *American Economic Review* 102.1 (2012): 131–66. http://dspace.mit.edu/openaccess-disseminate/1721.1/61749.

"Acid Test." *Economist* (November 23, 2013). http://www.economist.com/news/science-and-technology/21590349-worlds-seas-are-becoming-more-acidic-how-much-matters-not-yet-clear.

Alderman, Liz. "A Greener Champagne Bottle." *New York Times* (September 1, 2010): B1. http://www.nytimes.com/2010/09/01/business/energy-environment/01champagne.html.

Aldy, Joseph E., and William A. Pizer. "Comparability of Effort in International Climate Policy Architecture." The Harvard Project on Climate Agreements Discussion Paper 14–62 (January 2014). http://belfercenter.ksg.harvard.edu/files/dp62_aldy-pizer.pdf.

Allison, Graham T. *Nuclear Terrorism: The Ultimate Preventable Catastrophe*. Times Books, 2004. http://books.google.com/books?id=jDFY6FY4aakC&dq=isbn:0805076514.

Altshuller, A. P. "Assessment of the Contribution of Chemical Species to the Eye Irritation Potential of Photochemical Smog." *Journal of the Air Pollution Control Association* 28.6 (1978): 594–98. http://www.tandfonline.com/doi/abs/10.1080/00022470.1978.10470634#.UfkVeSTD99.

"Ambient (Outdoor) Air Quality and Health." World Health Organization (March 2014). http://www.who.int/mediacentre/factsheets/fs313/en/.

Anthoff, David, Robert J. Nicholls, Richard SJ Tol, and Athanasios T. Vafeidis. "Global and Regional Exposure to Large Rises in Sea-Level: A Sensitivity Analysis." Tyndall Centre for Climate Change Research Working Paper 96 (2006). http://www.tyndall.ac.uk/sites/default/files/wp96_0.pdf.

Anttila-Hughes, Jesse Keith and Solomon M. Hsiang. "Destruction, Disinvestment, and Death: Economic and Human Losses Following Environmental Disaster" (February 18, 2013). http://dx.doi.org/10.2139/ssrn.2220501.

Archer, David, Michael Eby, Victor Brovkin, Andy Ridgwell, Long Cao, Uwe Mikolajewicz, Ken Caldeira et al. "Atmospheric Lifetime of Fossil Fuel Carbon Dioxide." *Annual Review of Earth and Planetary Sciences* 37 (2009): 117–34. http://forecast.uchicago.edu/Projects/archer.2009.ann_rev_tail.pdf.

Arrhenius, Svante. "On the Influence of Carbonic Acid in the Air upon the Temperature of the Ground." *London, Edinburgh, and Dublin Philosophical Magazine and Journal of Science* 41.251 (1896): 237–76. http://www.tandfonline.com/doi/abs/10.1080/14786449608620846#.Ufl0myTD99A.

———. *Worlds in the Making: The Evolution of the Universe*. Harper, 1908. http://books.google.com/books/about/Worlds_in_the_making.html.

Arrow, K., M. Cropper, C. Gollier, B. Groom, G. Heal, R. Newell, W. Nordhaus et al. "Determining Benefits and Costs for Future Generations." *Science* 341.6144 (2013): 349–50. http://www.sciencemag.org/content/341/6144/349.full.

Artemieva, Natalia. "Solar System: Russian Skyfall." *Nature* 503.7475 (2013): 202–3. http://www.nature.com/nature/journal/v503/n7475/full/503202a.html.

Ashenfelter, Orley. "Measuring The Value of A Statistical Life: Problems and Prospects." *Economic Journal*, 116.510 (2006): C10–C23. http://www.nber.org/papers/w11916.

"The Asilomar Conference Recommendations on Principles for Research into Climate Engineering Techniques: Conference Report," prepared by the Asilomar Scientific Organizing Committee, Climate Institute (2010). http://climateresponsefund.org/images/Conference/finalfinalreport.pdf.

Avila, Lixion A., and John Cangialosi. "Tropical Cyclone Report: Hurricane Irene." National Hurricane Center (December 2011). http://www.nhc.noaa.gov/data/tcr/AL092011_Irene.pdf.

Axelrad, Daniel A., David C. Bellinger, Louise M. Ryan, and Tracey J. Woodruff. "Dose–Response Relationship of Prenatal Mercury Exposure and IQ: An Integrative Analysis of Epidemiologic Data." *Environmental Health Perspectives* 115. 4 (2007): 609. http://www.ncbi.nlm.nih.gov/pmc/articles/PMC1852694/.

Ballantyne, A. P., C. B. Alden, J. B. Miller, P. P. Tans, and J.W.C. White. "Increase in Observed Net Carbon Dioxide Uptake by Land and Oceans

During the Past 50 Years." *Nature* 488.7409 (2012): 70–72. http://www.nature.com/nature/journal/v488/n7409/full/nature11299.html.

Bamber, Jonathan L., Riccardo E. M. Riva, Bert L. A. Vermeersen, and Anne M. LeBrocq. "Reassessment of the Potential Sea-Level Rise from a Collapse of the West Antarctic Ice Sheet." *Science* 324.5929 (2009): 901–3. http://www.sciencemag.org/content/324/5929/901.short.

Barreca, Alan, Karen Clay, Olivier Deschenes, Michael Greenstone, and Joseph S. Shapiro. "Adapting to Climate Change: The Remarkable Decline in the U.S. Temperature-Mortality Relationship over the 20th Century." NBER Working Paper No. 18692 (January 2013). http://www.nber.org/papers/w18692.

Barrett, Scott. "Climate Treaties and Approaching Catastrophes." *Journal of Environmental Economics and Management* 66.2 (2013): 235–50. http://www.sciencedirect.com/science/article/pii/S0095069612001222.

———. *Environment and Statecraft: The Strategy of Environmental Treaty-Making*. Oxford University Press, 2003. http://global.oup.com/academic/product/environment-and-statecraft-9780199257331?cc=us&lang=en&tab=reviews.

———. "The Incredible Economics of Geoengineering." *Environmental and Resource Economics* 39 (2008): 45–54. http://link.springer.com/article/10.1007%2Fs10640-007-9174-8.

———. "Solar Geoengineering's Brave New World: Thoughts on the Governance of an Unprecedented Technology." *Review of Environmental Economics and Policy* 8.2 (2014): 249–69. http://reep.oxfordjournals.org/content/8/2/249.abstract.

Barrett, Scott, and Astrid Dannenberg. "Climate Negotiations under Scientific Uncertainty." *Proceedings of the National Academy of Sciences* 109.43 (2012): 17372–76. http://www.pnas.org/content/109/43/17372.short.

———. "Sensitivity of Collective Action to Uncertainty about Climate Tipping Points." *Nature Climate Change* 4.1 (2014): 36–39. http://www.nature.com/nclimate/journal/v4/n1/full/nclimate2059.html.

Barrett, Steven R. H., Rex E. Britter, and Ian A. Waitz. "Global Mortality Attributable to Aircraft Cruise Emissions." *Environmental Science & Technology* 44.19 (2010): 7736–42. http://pubs.acs.org/doi/abs/10.1021/es101325r.

Barro, Robert J. "Rare Disasters, Asset Price, and Welfare Costs." *American Economic Review* 99.1 (2009): 243–64. http://www.nber.org/papers/w13690.

Bazilian, Morgan, Ijeoma Onyeji, Michael Liebreich, Ian MacGill, Jennifer Chase, Jigar Shah, Dolf Gielen, Doug Arent, Doug Landfear, and Shi Zhengrong. "Re-considering the Economics of Photovoltaic Power." *Renewable Energy* 53 (2013): 329–38. http://www.sciencedirect.com/science/article/pii/S0960148112007641.

Bem, Daryl. "Self-Perception Theory." In *Advances in Experimental Social Psychology*, edited by Leonard Berkowitz, vol. 6. Academic Press, 1972. 1–62.

Benedick, Richard Elliot. *Ozone Diplomacy: New Directions in Safeguarding the Planet*. Harvard University Press, 1998.

Benenson Strategy Group and GS Strategy Group. "Recent Polling on Youth Voters" (July 2013). http://www.lcv.org/issues/polling/recent-polling-on-youth.pdf.

Berg, Paul. "Asilomar and Recombinant DNA." *Nobelprize.org* (July 17, 2013). http://www.nobelprize.org/nobel_prizes/chemistry/laureates/1980/berg-article.html.

Berg, Paul, D. Baltimore, S. Brenner, R. O. Robin, and M. F. Singer. "Summary Statement of the Asilomar Conference on Recombinant DNA Molecules." *Proceedings of the National Academy of Sciences of USA* 72.6 (1975): 1981–84. http://www.ncbi.nlm.nih.gov/pmc/articles/PMC432675/pdf/pnas00049-0007.pdf.

Bickel, J. Eric, and Shubham Agrawal. "Reexamining the Economics of Aerosol Geoengineering." *Climatic Change* (2011): 1–14. http://link.springer.com/article/10.1007/s10584-012-0619-x.

"Bicycling History." Cycling Embassy of Denmark. http://www.cycling-embassy.dk/facts-about-cycling-in-denmark/cycling-history/.

"Bike City." *Visitcopenhagen.com*. http://www.visitcopenhagen.com/copenhagen/bike-city.

Black, Fischer, and Robert B. Litterman. "Global Portfolio Optimization." *Financial Analysts Journal* 48.5 (1992): 28–43. http://www.jstor.org/discover/10.2307/4479577?uid=2&uid=4sid=21102739263593.

Blake, Eric S., Todd B. Kimberlain, Robert J. Berg, John P. Cangialosi, and John L. Beven II. *Tropical Cyclone Report: Hurricane Sandy*. National Hurricane Center (February 2013). http://www.nhc.noaa.gov/data/tcr/AL182012_Sandy.pdf.

Bluth, Gregg J. S., Scott D. Doiron, Charles C. Schnetzler, Arlin J. Krueger, and Louis S. Walter. "Global Tracking of the SO2 Clouds from the June, 1991 Mount Pinatubo Eruptions." *Geophysical Research Letters* 19.2 (1992): 151–54. http://so2.gsfc.nasa.gov/pdfs/Bluth_Pinatubo1991_GRL91GL02792.pdf.

Borgerson, Scott G. "The Coming Arctic Boom." *Foreign Affairs* (July/August 2013). http://www.foreignaffairs.com/articles/139456/scott-g-borgerson/the-coming-arctic-boom.

Bostrom, Nick, and Milan M. Ćirković, eds. *Global Catastrophic Risks*. Oxford University Press, 2011. http://www.global-catastrophic-risks.com/book.html.

Bradsher, Keith, and David Barboza. "Pollution from Chinese Coal Casts a Global Shadow." *New York Times* (June 11, 2006): A1. http://www.nytimes.com/2006/06/11/business/worldbusiness/11chinacoal.html.

Brauer, Michael, G. Hoek, H. A. Smit, J. C. de Jongste, J. Gerritsen, D. S. Postma, M. Kerkhof, and B. Brunekreef. "Air Pollution and Development of Asthma, Allergy and Infections in a Birth Cohort." *European Respiratory Journal* 29.5 (2007): 879–88. http://erj.ersjournals.com/content/29/5/879.full.

Brennan, Jason. *The Ethics of Voting*. Princeton University Press, 2011. http://press.princeton.edu/titles/9704.html.

British American Tobacco Australasia Limited and Ors v. the Commonwealth of Australia, no. S389/2411 (High Court of Australia 2012). http://www.hcourt.gov.au/cases/case-s389/2011.

Broecker, Wallace S. "Climatic Change: Are We on the Brink of a Pronounced Global Warming?" *Science* 189.4201 (1975). http://www.sciencemag.org/content/189/4201/460.abstract.

Brown, P. G., J. D. Assink, L. Astiz, R. Blaauw, M. B. Boslough, J. Borovicka, N. Brachet et al. "A 500-Kiloton Airburst over Chelyabinsk and an Enhanced Hazard from Small Impactors." *Nature* 503.7475 (2013): 238–41. http://www.nature.com/nature/journal/v503/n7475/full/nature12741.html.

Budescu, David V., Han-Hui Por, Stephen B. Broomell, and Michael Smithson. "The Interpretation of IPCC Probabilistic Statements around the World." *Nature Climate Change* 4.6 (2014): 508–12. http://www.nature.com/nclimate/journal/vaop/ncurrent/full/nclimate2194.html.

Butler, James H., and Stephen A. Montzka. "The NOAA Annual Greenhouse Gas Index (AGGI)." *NOAA Earth System Research Laboratory* (2013). http://www.esrl.noaa.gov/gmd/ccgg/aggi.html.

Caldeira, Ken, and Michael E. Wickett. "Oceanography: Anthropogenic Carbon and Ocean pH." *Nature* 425.6956 (2003): 365. http://www.nature.com/nature/journal/v425/n6956/full/425365a.html.

Carlowicz, M. "World of Change: Global Temperatures." NASA Earth Observatory (2010). http://earthobservatory.nasa.gov/Features/WorldOfChange/decadaltemp.php.

Chakravarty, Shoibal, Ananth Chikkatur, Heleen de Coninck, Stephen Pacala, Robert Socolow, and Massimo Tavoni. "Sharing Global CO_2 Emission Reductions among One Billion High Emitters." *Proceedings of the National Academy of Sciences* 106.29 (2009): 11884–88. http://cmi.princeton.edu/research/pdfs/one_billion_emitters.pdf.

Charney, Jule G., Akio Arakawa, D. James Baker, Bert Bolin, Robert E. Dickinson, Richard M. Goody, Cecil E. Leith, Henry M. Stommel, and Carl I. Wunsch. "Carbon Dioxide and Climate: A Scientific Assessment." National Academy of Sciences, 1979. http://www.atmos.ucla.edu/~brianpm/download/charney_report.pdf.

"China's 12GW Solar Market Outstripped All Expectations in 2013." *Bloomberg New Energy Finance* (January 23, 2014). http://about.bnef.com/files/2014/01/BNEF_PR_2014-01-23_China_Investment-final.pdf.

Christensen, Jens H., and Ole B. Christensen. "Climate Modelling: Severe Summertime Flooding in Europe." *Nature* 421.6925 (2003): 805–6. http://www.nature.com/nature/journal/v421/n6925/abs/421805a.html.

Christidis, Nikolaos, Peter A. Stott, Adam A. Scaife, Alberto Arribas, Gareth S. Jones, Dan Copsey, Jeff R. Knight, and Warren J. Tennant. "A New HadGEM3-A Based System for Attribution of Weather and Climate-Related Extreme Events." *Journal of Climate* 26.9 (2013). http://journals.ametsoc.org/doi/abs/10.1175/JCLI-D-12-00169.1.

Clark, Pilita. "What Climate Scientists Talk about Now." *Financial Times* (August 2, 2013). http://www.ft.com/intl/cms/s/2/4084c8ee-fa36-11e2-98e0-00144feabdc0.html#axzz2cQegckSd.

"Clean Energy: Calculations and References." *U.S. Environmental Protection Agency* (last updated April 2013). http://www.epa.gov/cleanenergy/energy-resources/refs.html.

Clements, Benedict J., David Coady, Stefania Fabrizio, Sanjeev Gupta, Trevor Serge, Coleridge Alleyne, and Carlo A. Sdralevich, eds. *Energy Subsidy Reform: Lessons and Implications*. International Monetary Fund, 2013. http://www.amazon.com/Energy-Subsidy-Reform-Lessons-Implications/dp/1475558112/.

"Climate Science: Vast Costs of Arctic Change." *Nature* 499.7459 (2013): 401–3. http://www.naturecom/nature/journal/v499/n7459/full/499401a.html.

CO_2Now. "Accelerating Rise of Atmospheric CO_2." http://co2now.org/Current-CO2/CO2-Trend/acceleration-of-atmospheric-co2.html.

Coase, Ronald H. "The Nature of the Firm." *Economica* 4.16 (1937): 386–405. http://onlinelibrary.wiley.com/doi/10.1111/j.1468-0335.1937.tb00002.x/full.

———. "The Problem of Social Cost." *The Journal of Law & Economics* 3 (1960): 1. http://heinonline.org/HOL/LandingPage?collection=journals&handle=hein.journals/jlecono3&div=2&id=&page=.

Collingridge, David. *The Social Control of Technology*. Pinter, 1980. http://www.amazon.com/Social-Control-Technology-David-Collingridge/dp/031273168X.

"Conversion Tables." Carbon Dioxide Information Analysis Center (last updated September 2012). http://cdiac.ornl.gov/pns/convert.html.

"Cool Roof Fact Sheet." *US Department of Energy Building Technologies* (August 2009). http://www1.eere.energy.gov/buildings/pdfs/cool_roof_fact_sheet.pdf.

"Copenhagen: Bike City for More Than a Century." *Denmark.dk*. http://denmark.dk/en/green-living/bicycle-culture/copenhagen-bike-city-for-more-than-a-century/.

Coumou, Dim, and Alexander Robinson. "Historic and Future Increase in the Global Land Area Affected by Monthly Heat Extremes." *Environmental Research Letters* 8 (2013). http://iopscience.iop.org/1748-9326/8/3/034018/article.

Coumou, Dim, Alexander Robinson, and Stefan Rahmstorf. "Global Increase in Record-Breaking Monthly-Mean Temperatures." *Climatic Change* 118.3–4 (2013): 771–82. http://link.springer.com/article/10.1007%2Fs10584-012-0668-1.

Cropper, Maureen L., Mark C. Freeman, Ben Groom, and William A. Pizer. "Declining Discount Rates." *American Economic Review: Papers and Proceedings* 104.5 (2014): 538–43. http://dx.doi.org/10.1257/aer.104.5.538.

Crutzen, Paul J. "Albedo Enhancement by Stratospheric Sulfur Injections: A Contribution to Resolve a Policy Dilemma?" *Climatic Change* 77.3 (2006): 211–20. http://link.springer.com/article/10.1007%2Fs10584-006-9101-y.

Cui, Ying, Lee R. Kump, Andy J. Ridgwell, Adam J. Charles, Christopher K. Junium, Aaron F. Diefendorf, Katherine H. Freeman, Nathan M. Urban, and Ian C. Harding. "Slow Release of Fossil Carbon during the Palaeocene-Eocene Thermal Maximum." *Nature Geoscience* 4.7 (2011): 481–85. http://www.nature.com/ngeo/journal/v4/n7/full/ngeo1179.html.

Curry, Judith A., Julie L. Schramm, and Elizabeth E. Ebert. "Sea Ice–Albedo Climate Feedback Mechanism." *Journal of Climate* 8.2 (1995): 240–47. http://journals.ametsoc.org/doi/abs/10.1175/1520-0442(1995)008%3C0240:SIACFM%3E2.0.CO%3B2.

Dales, John H. *Pollution, Property, and Prices: An Essay in Policy-Making and Economics*. University of Toronto Press, 1968.

"Defending Planet Earth: Near-Earth Object Surveys and Hazard Mitigation Strategies." National Academies Press, 2010. http://www.nap.edu/download.php?record_id=12842.

"Demoralized Trading: Stocks Break on Record Volume—Banking Support Starts Rally." *Wall Street Journal* (October 25, 1929).

Deschênes, Olivier, and Enrico Moretti. "Extreme Weather Events, Mortality, and Migration." *Review of Economics and Statistics* 91.4 (2009): 659–81. http://www.mitpressjournals.org/doi/pdf/10.1162/rest.91.4.659.

Diffenbaugh, Noah S., and Christopher B. Field. "Changes in Ecologically Critical Terrestrial Climate Conditions." *Science* 341.6145 (2013): 486–92. http://www.sciencemag.org/content/341/6145/486.full.

Dorbian, Christopher S., Philip J. Wolfe, and Ian A. Waitz. "Estimating the Climate and Air Quality Benefits of Aviation Fuel and Emissions Reductions." *Atmospheric Environment* 45.16 (2011): 2750–59. http://www.sciencedirect.com/science/article/pii/S1352231011001592.

Dreifus, Claudia. "Chasing the Biggest Story on Earth." *New York Times* (February 11, 2014): D5. http://www.nytimes.com/2014/02/11/science/the-sixth-extinction-looks-at-human-impact-on-the-environment.html.

Dutton, Ellsworth G., and John R. Christy. "Solar Radiative Forcing at Selected Locations and Evidence for Global Lower Tropospheric Cooling Following the Eruptions of El Chichón and Pinatubo." *Geophysical Research Letters* 19.23 (1992): 2313–16. http://onlinelibrary.wiley.com/doi/10.1029/92GL02495/abstract.

Dyer, Gwynne. *Climate Wars: The Fight for Survival as the World Overheats*. Scribe Publications, 2008. http://www.amazon.com/Climate-Wars-Fight-Survival-Overheats/dp/1851688145.

Eccles, Robert, Ioannis Ioannou, George Serafeim. "The Impact of a Corporate Culture of Sustainability on Corporate Behavior and Performance." HBS working paper 12–035 (November 25, 2011). http://www.hbs.edu/research/pdf/12-035.pdf.

"Economics of Ocean Acidification." International Atomic Energy Agency workshop (November 2012). http://medsea-project.eu/wp-content/uploads/2013/10/ebook-Economics-of-Ocean-Acidification.pdf.

Edmonds, David. *Would You Kill the Fat Man? The Trolley Problem and What Your Answer Tells Us about Right and Wrong*. Princeton University Press, 2013. http://press.princeton.edu/titles/10074.html.

Ellerman, Denny, Frank Convery, and Christian de Perthuis. *Pricing Carbon: The European Union Emissions Trading Scheme*. Cambridge University Press, 2010. http://www.cambridge.org/us/academic/subjects/economics/natural-resource-and-environmental-economics/pricing-carbon-european-union-emissions-trading-scheme.

Emanuel, Kerry A. "Downscaling CMIP5 Climate Models Shows Increased Tropical Cyclone Activity over the 21st Century." *Proceedings of the National Academy of Sciences* (July 8, 2013). http://www.pnas.org/content/early/2013/07/05/1301293110.abstract.

———. "Increasing Destructiveness of Tropical Cyclones over the Past 30 Years." *Nature* 436.7051 (2005): 686–88. http://www.nature.com/nature/journal/v436/n7051/abs/nature03906.html.

———. "MIT Climate Scientist Responds on Disaster Costs and Climate Change." FiveThirtyEight (March 31, 2014). http://fivethirtyeight.com/features/mit-climate-scientist-responds-on-disaster-costs-and-climate-change/.

Engber, Daniel. "You're Getting Warmer . . ." *Slate* (original story, 2007; reposted on August 20, 2013). http://www.slate.com/articles/health_and_science/science/2007/02/youre_getting_warmer_.html.

Fasullo, John T., and Kevin E. Trenberth. "A Less Cloudy Future: The Role of Subtropical Subsidence in Climate Sensitivity." *Science* 338.6108 (2012): 792–94. http://www.sciencemag.org/content/338/6108/792.

Fiscal Year 2014 Tentative Assessment Roll. NYC Finance (January 15, 2013). http://www.nyc.gov/html/dof/downloads/pdf/press_release/pr_assessment_14.pdf.

Fischer, Carolyn, Winston Harrington, and Ian WH Parry. "Should Automobile Fuel Economy Standards Be Tightened?" *Energy Journal* 28.4 (2007): 1–29. http://iaee.org/documents/vol28_4.pdf.

Fischetti, Mark. "New York City and the U.S. East Coast Must Take Drastic Action to Prevent Ocean Flooding." *Scientific American* 308.6 (2013): 58–67. http://www.scientificamerican.com/article.cfm?id=new-york-city-east-coast-drastic-actions-prevent-flooding-hurricane-sandy.

Fountain, Henry. "A Rogue Climate Experiment Outrages Scientists." *New York Times* (October 19, 2012). http://www.nytimes.com/2012/10/19/science/earth/iron-dumping-experiment-in-pacific-alarms-marine-experts.html.

Fourier, Jean-Baptiste Joseph. "Les Temperatures du Globe Terrestre et des espaces planetaires." *Mémoires de l'Académie des sciences de l'Institut de France* 7 (1827): 569–604. http://www.math.umn.edu/~mcgehee/Seminars/ClimateChange/references/Fourier1827.pdf.

———. "Remarques générales sur les températures du globe terrestre et des espaces planétaires." *Annales de Chimie et de Physique* 27 (1824): 136–67.

Fox-Penner, Peter. *Smart Power: Climate Change, the Smart Grid, and the Future of Electric Utilities*. Island Press, 2010. http://www.smartpowerbook.com/.

Franke, Andreas. "Analysis: German 2013 Wind, Solar Output Up 4% at Record 77TWh." *Platts* (January 7, 2014). http://www.platts.com/latest-news/electric-power/london/analysis-german-2013-wind-solar-power-output-26598276.

Frey, Bruno S., and Felix Oberholzer-Gee. "The Cost of Price Incentives: An Empirical Analysis of Motivation Crowding Out." *American Economic Review* 87:746–55 (1997). http://www.jstor.org/stable/2951373.

Friedlingstein, P., R. M. Andrew, J. Rogelj, G. P. Peters, J. G. Canadell, R. Knutti, G. Luderer, M. R. Raupach, M. Schaeffer, D. P. van Vuuren , and C. Le Quéré. "Persistent Growth of CO_2 Emissions and Implications for Reaching Climate Targets." *Nature Geoscience* 7.10: 709–15 (2014). http://www.nature.com/ngeo/journal/vaop/ncurrent/full/ngeo2248.html.

"Future climate change." U.S. EPA. http://www.epa.gov/climatechange/science/future.html.

Gardiner, Stephen. "Is 'Arming the Future' with Geoengineering Really the Lesser Evil? Some Doubts about the Ethics of Intentionally Manipulating the Climate System." In *Climate Ethics: Essential Readings*, edited by Stephen M. Gardiner, Simon Caney, Dale Jamieson, and Henry Shue. Oxford University Press, 2010. 284–312. http://papers.ssrn.com/sol3/papers.cfm?abstract_id=1357162.

Garrick, B. John. *Quantifying and Controlling Catastrophic Risks*. Academic Press, 2008. http://www.amazon.com/Quantifying-Controlling-Catastrophic-Risks-Garrick/dp/0123746019.

Gelman, Andrew, Nate Silver, and Aaron Edlin. "What Is the Probability Your Vote Will Make a Difference?" *Economic Inquiry* 50.2 (2012): 321–26. http://www.stat.columbia.edu/~gelman/research/published/probdecisive2.pdf.

Generation Foundation. "Stranded Carbon Assets: Why and How Carbon Risks Should Be Incorporated in Investment Analysis." White Paper (October 30, 2013). http://genfound.org/media/pdf-generation-foundation-stranded-carbon-assets-v1.pdf.

Giles, Jim. "Hacking the Planet, Who Decides?" *New Scientist* (March 29, 2010). http://www.newscientist.com/article/dn18713-hacking-the-planet-who-decides.html?full=true#.UioxwyTD99A.

———. "Scientific Uncertainty: When Doubt Is a Sure Thing." *Nature* 418.6897 (2002): 476–78. http://www.nature.com/nature/journal/v418/n6897/full/418476a.html.

Gillett, Nathan P., Vivek K. Arora, Kirsten Zickfeld, Shawn J. Marshall, and William J. Merryfield. "Ongoing Climate Change Following a Complete Cessation of Carbon Dioxide Emissions." *Nature Geoscience* 4.2 (2011): 83–87. http://www.nature.com/ngeo/journal/v4/n2/abs/ngeo1047.html.

Gillingham, Kenneth, Richard G. Newell, and Karen Palmer. "Energy Efficiency Economics and Policy." *Annual Review of Resource Economics* 1

(2009): 597–620. http://www.annualreviews.org/doi/abs/10.1146/annurev.resource.102308.124234.

Glaeser, Edward, Simon Johnson, and Andrei Shleifer. "Coase vs. the Coasians." *Quarterly Journal of Economics* 116.3 (2001): 853–99. http://qje.oxfordjournals.org/content/116/3/853.short.

"Global Market Outlook for Photovoltaics 2013–2017." *European Photovoltaic Industry Association* (May 2013). http://www.epia.org/fileadmin/user_upload/Publications/GMO_2013_-_Final_PDF.pdf.

"Global Warming: Who Pressed the Pause Button." *Economist* (March 8, 2014). http://www.economist.com/news/science-and-technology/21598610-slowdown-rising-temperatures-over-past-15-years-goes-being.

Goes, Marlos, Nancy Tuana, and Klaus Keller. "The Economics (or Lack Thereof) of Aerosol Geoengineering." *Climatic Change* 109.3–4 (2011): 719–44. http://www.aoml.noaa.gov/phod/docs/Goes_etal_2011.pdf.

Gollier, Christian. "Evaluation of Long-Dated Investments under Uncertain Growth Trend, Volatility and Catastrophes." CESifo Working Paper Series No. 4052 (2012). http://papers.ssrn.com/sol3/papers.cfm?abstract_id=2202094.

———. *Pricing the Planet's Future: The Economics of Discounting in an Uncertain World*. Princeton University Press, 2012. http://press.princeton.edu/titles/9894.html.

Gollier, Christian, and Martin L. Weitzman. "How Should the Distant Future Be Discounted When Discount Rates Are Uncertain?" *Economics Letters* 107.3 (2010): 350–53. http://scholar.harvard.edu/files/weitzman/files/howshoulddistantfuture.pdf.

Goodell, Jeff. *How to Cool the Planet: Geoengineering and the Audacious Quest to Fix Earth's Climate*. Houghton Mifflin Harcourt, 2010. http://books.google.com/books?id=5hAnBB-wmH4C.

Goulder, Lawrence H., and Andrew R. Schein. "Carbon Taxes vs. Cap and Trade: A Critical Review." NBER Working Paper No. 19338 (August 2013). http://www.nber.org/papers/w19338.

Greenberg, Max, Denise Robbins, and Shauna Theel. "Media Sowed Doubt in Coverage of UN Climate Report." MediaMatters.org (October 10, 2013). http://mediamatters.org/research/2013/10/10/study-media-sowed-doubt-in-coverage-of-un-clima/196387.

"A Green Light." *Economist* (March 29, 2014). http://www.economist.com/news/business/21599770-companies-are-starting-open-up-about-their-environmental-risks-they-need-do-more-green.

Greenstone, Michael, Elizabeth Kopits, and Ann Wolverton. "Developing a Social Cost of Carbon for US Regulatory Analysis: A Methodology and Interpretation." *Review of Environmental Economics and Policy* 7.1 (2013): 23–46. http://reep.oxfordjournals.org/content/7/1/23.abstract.

Gunther, Marc. *Suck It Up: How Capturing Carbon from the Air Can Help Solve the Climate Crisis*. Amazon Kindle Single, 2012. http://www.marcgunther.com/suck-it-up-my-book-about-climate-change-geoengineering-and-air-capture-of-co2/.

Gurwick, Noel P., Lisa A. Moore, Charlene Kelly, and Patricial Elias. "A Systematic Review of Biochar Research, with a Focus on Its Stability in Situ and Its Promise as a Climate Mitigation Strategy." *Plos One* 8.9 (2013). http://www.plosone.org/article/info%3Adoi%2F10.1371%2Fjournal.pone.0075932.

Guy, Sophie, Yoshihisa Kashima, Iain Walker, and Saffron O'Neill. "Comparing the Atmosphere to a Bathtub: Effectiveness of Analogy for Reasoning about Accumulation." *Climatic Change* 121.4 (2013): 579–94. http://link.springer.com/article/10.1007/s10584-013-0949-3.

Haagen-Smit, A. J. "Chemistry and Physiology of Los Angeles smog." *Industrial and Engineering Chemistry* 44.6 (1952): 1342–46. http://pubs.acs.org/doi/abs/10.1021/ie50510a045?journalCode=iechad.

Hamilton, Clive. *Earthmasters: The Dawn of the Age of Climate Engineering*. Yale University Press, 2013. http://books.google.com/books?lr=&id=x61F2HkKtVEC.

Hammar, H., T. Sterner, and S. Åkerfeldt. "Sweden's CO_2 Tax and Taxation Reform Experiences." In *Reducing Inequalities: A Sustainable Development Challenge*, edited by R. Genevey, R. Pachauri, L., Tubiana. New Delhi: TERI Press (2013): 169–74. http://www.efdinitiative.org/publications/swedens-co2-tax-and-taxation-reform-experiences.

Hansen, James, and Makiko Sato. "Climate Sensitivity Estimated from Earth's Climate History." NASA Goddard Institute for Space Studies and Columbia University Earth Institute. New York (May 2012). http://www.columbia.edu/~jeh1/mailings/2012/20120508_ClimateSensitivity.pdf.

Hansen, James, Makiko Sato, Pushker Kharecha, David Beerling, Valerie Masson-Delmotte, Mark Pagani, Maureen Raymo, Dana L. Royer, and James C. Zachos. "Target Atmospheric CO_2: Where Should Humanity Aim?" *NASA Goddard Institute for Space Studies, Columbia University Earth Institute* (2008). http://www.columbia.edu/~jeh1/2008/TargetCO2_20080407.pdf.

Hardin, Garrett. "Tragedy of the Commons." *Science* 162.3859 (1968): 1243–48. http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.124.3859&rep=rep1&type=pdf.

Harvey, L.D.D. "Mitigating the Atmospheric CO_2 Increase and Ocean Acidification by Adding Limestone Powder to Upwelling Regions." *Journal of Geophysical Research: Oceans (1978–2012)* 113.C4 (2008). http://onlinelibrary.wiley.com/doi/10.1029/2007JC004373/abstract.

Heal, Geoffrey M., and Antony Millner. "Agreeing to Disagree on Climate Policy." *Proceedings of the National Academy of Sciences* 111.10 (2014): 3695–8. http://www.pnas.org/content/early/2014/02/19/1315987111.short.

———. "Uncertainty and Decision in Climate Change Economics." NBER Working Paper No. 18929 (2013). http://www.nber.org/papers/w18929.

Heal, Geoffrey M., and Jisung Park. "Feeling the Heat: Temperature, Physiology and the Wealth of Nations." National Bureau of Economic Research (NBER) Working Paper No. w19725 (2013). http://www.nber.org/papers/w19725.

Heckendorn, P., D. Weisenstein, S. Fueglistaler, B. P. Luo, E. Rozanov, M. Schraner, L. W. Thomason, and T. Peter. "The Impact of Geoengineering Aerosols on Stratospheric Temperature and Ozone." *Environmental Research Letters* 4.4 (2009). http://iopscience.iop.org/1748-9326/4/4/045108/fulltext/.

Heffernan, Margaret. *Willful Blindness*. Walker, 2011. http://books.google.com/books?id=3rQiXitkUpMC.

High-End cLimate Impacts and eXtremes (HELIX). http://www.HELIXclimate.eu.

Hogan, William W. "Scarcity Pricing: More on Locational Operating Reserve Demand Curves" Harvard Electricity Policy Group. Presentation, San Diego, March 2013. http://www.hks.harvard.edu/fs/whogan/Hogan_hepg_031309r.pdf.

House of Commons Science and Technology Committee. "The Regulation of Geoengineering." London, UK (2010). http://www.publications.parliament.uk/pa/cm200910/cmselect/cmsctech/221/221.pdf.

Howard, Peter. "Omitted Damages: What's Missing from the Social Cost of Carbon." Cost of Carbon Project (2014). http://costofcarbon.org/files/Omitted_Damages_Whats_Missing_From_the_Social_Cost_of_Carbon.pdf.

Hsiang, Solomon M., Marshall Burke, and Edward Miguel. "Quantifying the Influence of Climate on Human Conflict." *Science* 341.6151 (2013): 1235367. http://www.sciencemag.org/content/341/6151/1235367.

Hsiang, Solomon M., Kyle C. Meng, and Mark A. Cane. "Civil Conflicts Are Associated with the Global Climate." *Nature* 476.7361 (2011): 438–41. http://www.nature.com/nature/journal/v476/n7361/full/nature10311.html.

IGBP, IOC, SCOR. "Ocean Acidification Summary for Policymakers—Third Symposium on the Ocean in a High-CO_2 World." International Geosphere-Biosphere Programme, Stockholm, Sweden (2013).

http://www.igbp.net/download/18.30566fc6142425d6c91140a/1384420272253/OA_spm2-FULL-lorez.pdf.

Immerzeel, Walter W., Ludovicus P. H. van Beek, and Marc F. P. Bierkens. "Climate Change Will Affect the Asian Water Towers." *Science* 328.5984 (2010): 1382–85. http://www.sciencemag.org/content/328/5984/1382.full.

"Incorporating Sea-Level Change Considerations in Civil Works Programs." USACE EC 1165–2–212 (2011). http://www.flseagrant.org/wp-content/uploads/2012/02/USACE_SLR_policy_2011-2013.pdf.

Inman, Mason, "Carbon Is Forever." *Nature Reports Climate Change* 12 (2008). http://www.nature.com/climate/2008/0812/full/climate.2008.122.html.

Intergovernmental Panel on Climate Change (IPCC). *Climate Change 1992: The Supplementary Report to the IPCC Scientific Assessment* (1992). http://www.ipcc.ch/publications_and_data/publications_ipcc_supplementary_report_1992_wg1.shtml.

———. *IPCC Fifth Assessment Report: Climate Change 2013* (AR5) (2013–14). http://www.ipcc.ch/report/ar5/.

———. *IPCC First Assessment Report* (1990).

———. *IPCC Fourth Assessment Report: Climate Change 2007* (AR4)(2007). http://www.ipcc.ch/publications_and_data/ar4/syr/en/contents.html.

———. *IPCC Second Assessment Report: Climate Change 1995 (SAR)* (1995). http://www.ipcc.ch/pdf/climate-changes-1995/ipcc-2nd-assessment/2nd-assessment-en.pdf.

———. *IPCC Third Assessment Report: Climate Change 2001 (TAR)* (2001). http://www.grida.no/publications/other/ipcc_tar/.

———. *Special Report: Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation* (2012). http://ipcc-wg2.gov/SREX/images/uploads/SREX-All_FINAL.pdf.

———. *IPCC Special Report on Emissions Scenarios (SRES)* (2000). https://www.ipcc.ch/pdf/special-reports/spm/sres-en.pdf.

"Interview of Virgin Group Ltd Chairman Sir Richard Branson by *The Economist* New York Bureau Chief Matthew Bishop," transcript from U.S. Department of State conference on the "Global Impact Economy," on April 20, 2012. http://www.state.gov/s/partnerships/releases/2012/189100.htm.

"Irene by the Numbers." *NOAA* (August 2011). http://www.noaa.gov/images/Hurricane%20Irene%20by%20the%20Numbers%20-%20Factoids_V4_083111.pdf.

Jacobsen, Grant D., Matthew J. Kotchen, and Michael P. Vandenbergh. "The Behavioral Response to Voluntary Provision of an Environmental Public Good: Evidence from Residential Electricity Demand."

European Economic Review 56 (2012): 946–60. http://www.nber.org/papers/w16608.

Jacobsen, Mark R. "Evaluating U.S. Fuel Economy Standards in a Model with Producer and Household Heterogeneity." *American Economic Journal: Economic Policy* 5.2 (2013): 148–87. http://www.aeaweb.org/articles.php?doi=10.1257/pol.5.2.148.

Jacobson, Mark Z., and John E. Ten Hoeve. "Effects of Urban Surfaces and White Roofs on Global and Regional Climate." *Journal of Climate* 24.3 (2012): 1028–44. http://journals.ametsoc.org/doi/abs/10.1175/JCLI-D-11-00032.1?journalCode=clim.

Jaffé, Rudolf, Yan Ding, Jutta Niggermann, Anssi V. Vähätalo, Aron Stubbins, Robert G. M. Spencer, John Campbell, and Thorsten Dittmar. "Global Charcoal Mobilization from Soils via Dissolution and Riverine Transport to the Oceans." *Science* 340.6130 (2013): 345–47. http://www.sciencemag.org/content/340/6130/345.full.

Jensen, Robert T., and Nolan H. Miller. "Giffen Behavior and Subsistence Consumption." *American Economic Review* 98.4 (2008): 1553. http://www.aeaweb.org/articles.php?doi=10.1257/aer.98.4.1553.

Jerrett, Michael, Richard T. Burnett, C. Arden Pope III, Kazuhiko Ito, George Thurston, Daniel Krewski, Yuanli Shi, Eugenia Calle, and Michael Thun. "Long-Term Ozone Exposure and Mortality." *New England Journal of Medicine* 360.11 (2009): 1085–95. http://www.nejm.org/doi/full/10.1056/NEJMoa0803894.

Johansson, Bengt. "Economic Instruments in Practice 1: Carbon Tax in Sweden." *Swedish Environmental Protection Agency* (2001). http://www.oecd.org/science/inno/2108273.pdf.

"John Tyndall." *NASA Earth Observatory.* http://earthobservatory.nasa.gov/Features/Tyndall/.

Jones, Andy, Jim Haywood, and Olivier Boucher. "Climate Impacts of Geoengineering Marine Stratocumulus Clouds." *Journal of Geophysical Research: Atmospheres (1984–2012)* 114.D10 (2009). http://onlinelibrary.wiley.com/doi/10.1029/2008JD011450/abstract.

Jones, Andy, Jim M. Haywood, Kari Alterskjær, Olivier Boucher, Jason N. S. Cole, Charles L. Curry, Peter J. Irvine et al. "The Impact of Abrupt Suspension of Solar Radiation Management (Termination Effect) in Experiment G2 of the Geoengineering Model Intercomparison Project (GeoMIP)." *Journal of Geophysical Research: Atmospheres* 118.17 (2013): 9743–52. http://onlinelibrary.wiley.com/doi/10.1002/jgrd.50762/abstract.

Jones, Gregory V., Michael A. White, Owen R. Cooper, and Karl Storchmann. "Climate Change and Global Wine Quality." *Climatic Change* 73.3 (2005): 319–43. http://www.recursosdeenologia.com/docs/2005/2005_climate_change_and_global_wine_quality.pdf.

Jones, Morgan T., Stephen J. Sparks, and Paul J. Valdes. "The Climatic Impact of Supervolcanic Ash Blankets." *Climate Dynamics* 29.6 (2007): 553–64. http://link.springer.com/article/10.1007%2Fs00382-007-0248-7.

Joos, Fortunat and M. Bruno. "A Short Description of the Bern Model." (September 1996). http://www.climate.unibe.ch/~joos/model_description/model_description.html.

Joughin, Ian, Benjamin E. Smith, and Brooke Medley. "Marine Ice Sheet Collapse Potentially Under Way for the Thwaites Glacier Basin, West Antarctica." *Science* 344.6185 (2014): 735–38. http://www.sciencemag.org/content/344/6185/735.abstract.

Kahn, Matthew E. *Climatopolis: How Our Cities Will Thrive in the Hotter Future*. Basic Books, 2010. http://books.google.com/books/about/Climatopolis.html?id=nQjxjwEACAAJ.

Kahneman, Daniel. *Thinking, Fast and Slow*. New York: Farrar, Straus and Giroux, 2011. http://www.amazon.com/Thinking-Fast-Slow-Daniel-Kahneman/dp/0374533555.

Kahneman, Daniel, and Amos Tversky. "Prospect Theory: An Analysis of Decision under Risk." *Econometrica* 47.2 (1979): 263–92. http://pages.uoregon.edu/harbaugh/Readings/GBE/Risk/Kahneman%201979%20E,%20Prospect%20Theory.pdf.

———. "Subjective Probability: A Judgment of Representativeness." *Cognitive Psychology* 3.3 (1972): 430–54. http://www.sciencedirect.com/science/article/pii/0010028572900163.

Kahneman, Daniel, Jack L. Knetsch, and Richard H. Thaler. "Anomalies: The Endowment Effect, Loss Aversion, and Status Quo Bias." *Journal of Economic Perspectives* 5.1 (1991): 193–206. http://econ.ucdenver.edu/beckman/Econ%204001/thaler-loss-aversion.pdf.

———. "Experimental Tests of the Endowment Effect and the Coase theorem." *Journal of Political Economy* 98.6 (1990): 1325–48. http://teaching.ust.hk/~bee/papers/040918/1990-Kahneman-endowment_effect_coase_theorem.pdf.

Kaplan, Thomas. "Homeowners in Flood Zones Opt to Rebuild, Not Move." *New York Times* (April 27, 2013): A17. http://www.nytimes.com/2013/04/27/nyregion/new-yorks-storm-recovery-plan-gets-federal-approval.html.

Karplus, Valerie J., Sergey Paltsev, Mustafa Babiker, and John M. Reilly. "Should a Vehicle Fuel Economy Standard Be Combined with an Economy-Wide Greenhouse Gas Emissions Constraint? Implications for Energy and Climate Policy in the United States." *Energy Economics* 36 (2013): 322–33. http://www.sciencedirect.com/science/article/pii/S0140988312002150.

Keeling, C. D., S. C. Piper, R. B. Bacastow, M. Wahlen, T. P. Whorf, M. Heimann, and H. J. Meijer. *Exchanges of Atmospheric CO_2 and I3CO_2 with the Terrestrial Biosphere and Oceans from 1978 to 2013. Global Aspects.* SIO Reference Series, No. 01–06, Scripps Institution of Oceanography, San Diego (accessed 2013). http://scrippsco2.ucsd.edu/data/in_situ_co2/monthly_mlo.csv.

Keith, David W. *A Case for Climate Engineering*. A Boston Review Book / MIT Press, 2013. http://mitpress.mit.edu/books/case-climate-engineering.

———. "Geoengineering the Climate: History and Prospect." *Annual Review of Energy and the Environment* 25.1 (2000): 245–84. http://www.annualreviews.org/doi/abs/10.1146/annurev.energy.25.1.245?journalCode=energy.2.

———. "Photophoretic Levitation of Engineered Aerosols for Geoengineering." *Proceedings of the National Academy of Sciences* 107.38 (2010): 16428–31. http://www.pnas.org/content/107/38/16428.full.

Kemp, A. C., and B. P. Horton. "Contribution of Relative Sea-Level Rise to Historical Hurricane Flooding in New York City." *Journal of Quaternary Science* 28.6 (2013): 537–41. http://onlinelibrary.wiley.com/doi/10.1002/jqs.2653/abstract.

Keohane, Nathaniel O. "Cap and Trade, Rehabilitated: Using Tradable Permits to Control U.S. Greenhouse Gases." *Review of Environmental Economics and Policy* 3.1 (2009): 42–62. http://reep.oxfordjournals.org/content/3/1/42.abstract.

Keohane, Nathaniel O., and Gernot Wagner. "Judge a Carbon Market by Its Cap, Not Its Prices." *Financial Times* (July 17, 2013). http://www.ft.com/cms/s/0/de783c62-ee23-11e2-816e-00144feabdc0.html.

Khatiwala, S., F. Primeau, and T. Hall. "Reconstruction of the History of Anthropogenic CO_2 Concentrations in the Ocean." *Nature* 462.7271 (2009): 346–49. http://www.nature.com/nature/journal/v462/n7271/full/nature08526.html.

Kirk-Davidoff, Daniel B., Eric J. Hintsa, James G. Anderson, and David W. Keith. "The Effect of Climate Change on Ozone Depletion through Changes in Stratospheric Water Vapour." *Nature* 402.6760 (1999): 399–401. http://www.nature.com/nature/journal/v402/n6760/abs/402399a0.html.

Kirschbaum, Erik. "Germany Sets New Solar Power Record, Institute Says." Reuters (May 2012). http://www.reuters.com/article/2012/05/26/us-climate-germany-solaridUSBRE84P0FI20120526.

Klepper, Gernot, and Wilfried Rickels. "The Real Economics of Climate Engineering." *Economics Research International* 2012.316564 (2012). http://www.hindawi.com/journals/econ/2012/316564/.

Klein, Naomi. "Capitalism vs. the Climate." *Nation* (November 28, 2011). http://www.thenation.com/article/164497/capitalism-vs-climate.

———. *This Changes Everything: Capitalism vs. the Climate*. Penguin, 2014.

Klier, Thomas, and Joshua Linn. "New-Vehicle Characteristics and the Cost of the Corporate Average Fuel Economy Standard." *RAND Journal of Economics* 43.1 (2012): 186–213. http://www.rff.org/rff/Documents/RFF-DP-10-50.pdf.

Klingman, William K., and Klingman, Nicholas P. *The Year without a Summer: 1816 and the Volcano That Darkened the World and Changed History.* St. Martin's Press, 2013.

Knight, Frank H. *Risk, Uncertainty, and Profit*. Hart, Schaffner and Marx, 1921. http://www.econlib.org/library/Knight/knRUP.html.

Knutti, Reto, and Gabriele C. Hegerl. "The Equilibrium Sensitivity of the Earth's Temperature to Radiation Changes." *Nature Geoscience* 1.11 (2008): 735–43. http://www.nature.com/ngeo/journal/v1/n11/abs/ngeo337.html.

Kolbert, Elizabeth. *Field Notes from a Catastrophe: Man, Nature, and Climate Change*. Bloomsbury, 2006. http://books.google.com/books?id=Bd-uEKO7g4oC.

———. "Hosed." *New Yorker* (November 16, 2009). http://www.newyorker.com/arts/critics/books/2009/11/16/091116crbo_books_kolbert.

———. *The Sixth Extinction: An Unnatural History.* Henry Holt, 2014.

Kopp, Robert E., and Bryan K. Mignone. "The U.S. Government's Social Cost of Carbon Estimates after Their First Two Years: Pathways for Improvement." *Economics: The Open-Access, Open-Assessment E-Journal* 6 (2012–15): 1–41. http://dx.doi.org/10.5018/economics-ejournal.ja.2012-15.

Kravitz, Ben, Alan Robock, Luke Oman, Georgiy Stenchikov, and Allison B. Marquardt. "Sulfuric Acid Deposition from Stratospheric Geoengineering with Sulfate Aerosols." *Journal of Geophysical Research: Atmospheres (1984–2012)* 114.D14 (2009). http://onlinelibrary.wiley.com/doi/10.1029/2009JD011918/abstract.

Krosnick, Jon A. "The Climate Majority." *New York Times* (June 8, 2010). http://www.nytimes.com/2010/06/09/opinion/09krosnick.html?pagewanted=all&_r=1&.

"Kyoto Protocol to the united nations framework convention on climate change." *United Nations Framework Convention on Climate Change* (1997). http://unfccc.int.

Laibson, David. "Golden Eggs and Hyperbolic Discounting." *Quarterly Journal of Economics* 112.2 (1997): 443–77. http://scholar.harvard.edu/laibson/publications/golden-eggs-and-hyperbolic-discounting.

Latham, John, Keith Bower, Tom Choularton, Hugh Coe, Paul Connolly, Gary Cooper, Tim Craft et al. "Marine Cloud Brightening." *Philosophical Transactions of the Royal Society: Mathematical, Physical and Engineering Sciences* 370.1974 (2012): 4217–62. http://rsta.royalsocietypublishing.org/content/370/1974/4217.short.

Latham, John, Philip Rasch, Chih-Chieh Chen, Laura Kettles, Alan Gadian, Andrew Gettelman, Hugh Morrison, Keith Bower, and Tom Choularton. "Global Temperature Stabilization via Controlled Albedo Enhancement of Low-Level Maritime Clouds." *Philosophical Transactions of the Royal Society* 366.1882 (2008): 3969–87. http://rsta.royalsocietypublishing.org/content/366/1882/3969.short.

Lenton, Timothy M., Hermann Held, Elmar Kriegler, Jim W. Hall, Wolfgang Lucht, Stefan Rahmstorf, and Hans Joachim Schellnhuber. "Tipping Elements in the Earth's Climate System." *Proceedings of the National Academy of Sciences* 105.6 (2008): 1786–93. http://www.pnas.org/content/105/6/1786.full.pdf.

Le Quéré, C., G. P. Peters, R. J. Andres, R. M. Andrew, T. Boden, P. Ciais, P. Friedlingstein et al. "Global Carbon Budget 2013." *Earth System Science Data Discussions* 6.1 (2014): 235–63. http://www.earth-syst-sci-data.net/6/235/2014/essd-6-235-2014.html.

Leurig, Sharlene, and Andrew Dlugolecki. *Insurer Climate Risk Disclosure Survey: 2012 Findings and Recommendations*. Ceres (March 2013). http://www.ceres.org/resources/reports/naic-report.

Levitt, Steven, and Stephen Dubner. *SuperFreakonomics*. Harper Collins, 2010. http://www.superfreakonomicsbook.com/.

Lewis, Robert and Al Shaw. "After Sandy, Government Lends to Rebuild in Flood Zones." *ProPublica* and WNYC (March 2013). http://www.propublica.org/article/after-sandy-government-lends-to-rebuild-in-flood-zones.

Li, Qingxiang, Jiayou Huang, Zhihong Jiang, Liming Zhou, Peng Chu, and Kaixi Hu. "Detection of Urbanization Signals in Extreme Winter Minimum Temperature Changes over Northern China." *Climatic Change* 122.4 (2014): 595–608. http://link.springer.com/article/10.1007/s10584-013-1013-z.

Liebreich, Michael. "Global Trends in Clean Energy Investment." *Bloomberg New Energy Finance.* Presentation given at the Clean Energy Ministerial in Delhi (April 17, 2013). http://about.bnef.com/presentations/global-trends-in-clean-energy-investment/.

Liger-Belair, Gérard, Marielle Bourget, Sandra Villaume, Philippe Jeandet, Hervé Pron, and Guillaume Polidori. "On the Losses of Dissolved CO_2 during Champagne Serving." *Journal of Agricultural and Food Chemistry* 58.15 (2010): 8768–75. http://pubs.acs.org/doi/abs/10.1021/jf101239w.

Liger-Belair, Gérard, Guillaume Polidori, and Philippe Jeandet. "Recent Advances in the Science of Champagne Bubbles." *Chemical Society Reviews* 37.11 (2008): 2490–511. http://www.ncbi.nlm.nih.gov/pubmed/18949122.

Lin, Ning, Kerry Emanuel, Michael Oppenheimer, and Erik Vanmarcke. "Physically Based Assessment of Hurricane Surge Threat under Climate Change." *Nature Climate Change* 2 (2012): 462–67. http://www.nature.com/nclimate/journal/v2/n6/abs/nclimate1389.html.

Litterman, Robert B. "The Other Reason for Divestment." Ensia.com (November 5, 2013). http://ensia.com/voices/the-other-reason-for-divestment/.

———. "What Is the Right Price for Carbon Emissions?" *Regulation* (Summer 2013). http://www.cato.org/sites/cato.org/files/serials/files/regulation/2013/6/regulation-v36n2-1-1.pdf.

Lott, Fraser C., Nikolaos Christidis, and Peter A. Stott. "Can the 2011 East African Drought Be Attributed to Human-Induced Climate Change?" *Geophysical Research Letters* 40.6 (2013): 1177–81. http://onlinelibrary.wiley.com/doi/10.1002/grl.50235/abstract.

Lovett, Ken. "Gov. Cuomo: Sandy as Bad as Anything I've Experienced in New York." *New York Daily News* (October 30, 2012). http://www.nydailynews.com/blogs/dailypolitics/2012/10/gov-cuomo-sandy-as-bad-as-anything-ive-experienced-in-new-york.

Lynas, Mark. *Six Degrees: Our Future on a Hotter Planet*. Fourth Estate, 2007.

Machiavelli, Niccolò. *The Prince*. 1532. Chapter 11. Translated by W. K. Marriott in 1908. http://www.constitution.org/mac/prince06.htm.

MacKay, David J.C. *Sustainable Energy—without the Hot Air.* UIT Cambridge, 2009. www.withouthotair.com.

Major, Julie, Johannes Lehmann, Marco Rondon, and Christine Goodale. "Fate of Soil-Applied Black Carbon: Downward Migration, Leaching and Soil Respiration." *Global Change Biology* 16 (2010): 1366–79. http://www.css.cornell.edu/faculty/lehmann/publ/GlobalChangeBiol%2016,%201366-1379,%202010%20Major.pdf.

Margolis, Joshua D., Hillary Anger Elfenbein, and James P. Walsh. "Does It Pay to Be Good . . . and Does It Matter? A Meta-Analysis of the Relationship between Corporate Social and Financial Performance." SSRN Working paper (March 1, 2009). http://ssrn.com/abstract=1866371.

Marlon, J.R., Leiserowitz, A., and Feinberg, G. "Scientific and Public Perspectives on Climate Change." Yale University, Yale Project on Climate Change Communication (2013). http://environment.yale.edu/climate-communication/files/ClimateNote_Consensus_Gap_May2013_FINAL6.pdf.

Mastrandrea, Michael D., Katharine J. Mach, Gian-Kasper Plattner, Ottmar Edenhofer, Thomas F. Stocker, Christopher B. Field, Kristie L. Ebi, and Patrick R. Matschoss. "The IPCC AR5 Guidance Note on Consistent Treatment of Uncertainties: A Common Approach across the Working Groups." *Climatic Change* 108.4 (2011): 675–91. http://link.springer.com/content/pdf/10.1007/s10584-011-0178-6.pdf.

Matthews, H. Damon, and Ken Caldeira. "Transient Climate–Carbon Simulations of Planetary Geoengineering." *Proceedings of the National Academy of Sciences* 104.24 (2007): 9949–54. http://www.pnas.org/content/104/24/9949.short.

Matthews, H. Damon, Nathan P. Gillett, Peter A. Stott, and Kirsten Zickfeld. "The Proportionality of Global Warming to Cumulative Carbon Emissions." *Nature* 459.7248 (2009): 829–32. http://www.nature.com/nature/journal/v459/n7248/full/nature08047.html.

Mauna Loa Observatory, National Oceanic and Atmospheric Administration (NOAA). http://www.esrl.noaa.gov/gmd/obop/mlo/.

McClellan, Justin, David W. Keith, and Jay Apt. "Cost Analysis of Stratospheric Albedo Modification Delivery Systems." *Environmental Research Letters* 7.3 (2012): 034019. http://iopscience.iop.org/1748-9326/7/3/034019.

McCormick, M. Patrick, Larry W. Thomason, and Charles R. Trepte. "Atmospheric Effects of the Mt. Pinatubo Eruption." *Nature* 373.6513 (1995): 399–404. http://www.nature.com/nature/journal/v373/n6513/abs/373399a0.html.

McGranahan, Gordon, Deborah Balk, and Bridget Anderson. "The Rising Tide: Assessing the Risks of Climate Change and Human Settlements in Low Elevation Coastal Zones." *Environment and Urbanization* 19.1 (2007): 17–37. http://eau.sagepub.com/content/19/1/17.

McKibben, Bill. "Global Warming's Terrifying New Math." *Rolling Stone* (August 2, 2012). http://www.rollingstone.com/politics/news/global-warmings-terrifying-new-math-20120719.

Meehl, Gerald A., Aixue Hu, Claudia Tebaldi, Julie M. Arblaster, Warren M. Washington, Haiyan Tang, Benjamin M. Sanderson, Toby Ault, Warren G. Strand, and James B. White III. "Relative Outcomes of Climate Change Mitigation Related to Global Temperature versus Sea-Level Rise." *Nature Climate Change* 2 (2012): 576–80. http://www.nature.com/nclimate/journal/v2/n8/full/nclimate1529.html.

Mehra, Rajnish. "The Equity Premium Puzzle: A Review." *Foundations and Trends in Finance*, 2.1 (2008): 1–81. http://papers.ssrn.com/sol3/papers.cfm?abstract_id=1624986.

Melillo, Jerry M., Terese (T.C.) Richmond, and Gary W. Yohe, eds.: *Climate Change Impacts in the United States: The Third National Climate Assessment*. U.S. Global Change Research Program (2014).

Mellström, Carl, and Magnus Johannesson. "Crowding Out in Blood Donation: Was Titmuss Right?" *Journal of the European Economic Association* 6.4 (2008): 845–63. http://onlinelibrary.wiley.com/doi/10.1162/JEEA.2008.6.4.845/abstract.

Mendelsohn, Robert, Kerry Emanuel, Shun Chonabayashi, and Laura Bakkensen. "The Impact of Climate Change on Global Tropical Cyclone Damage." *Nature Climate Change* 2.3 (2012): 205–9. http://www.nature.com/nclimate/journal/v2/n3/full/nclimate1357.html.

Mendelsohn, Robert, Wendy Morrison, Michael E. Schlesinger, and Natalia G. Andronova. "Country-Specific Market Impacts of Climate Change." *Climatic Change* 45.3–4 (2000): 553–69. http://link.springer.com/article/10.1023%2FA%3A1005598717174.

Meng, Kyle C. "Estimating the Cost of Climate Policy Using Prediction Markets and Lobbying Records." Ph.D. dissertation, Columbia University, 2013. https://dl.dropboxusercontent.com/u/3015077/Website/Meng_cap_trade_Aug2013.pdf.

Menon, Surabi, Hashem Akbari, Sarith Mahanama, Igor Sednev, and Ronnen Levinson. "Radiative Forcing and Temperature Response to Changes in Urban Albedos and Associated CO_2 Offsets," *Environmental Research Letters* 5.1 (2010). http://iopscience.iop.org/1748-9326/5/1/014005.

Metcalf, Gilbert E., "Designing a Carbon Tax to Reduce U.S. Greenhouse Gas Emissions." *Review of Environmental Economics and Policy* 3.1 (2009): 63–83. http://reep.oxfordjournals.org/content/3/1/63.abstract.

Metz, Tim, Alan Murray, Thomas E. Ricks, and Beatrice E. Garcia. "The Crash of '87: Stocks Plummet 508 Amid Panicky Selling." *Wall Street Journal* (October 20, 1987). http://online.wsj.com/article/SB100008723963904447348045780645715935598196.html.

Miller, Bruce G. *Coal Energy Systems*. Elsevier Academic Press, 2005. http://books.google.com/books/about/Coal_Energy_Systems.html?id=PYyJEEyJN94C.

Millner, Antony, Simon Dietz, and Geoffrey Heal. "Scientific Ambiguity and Climate Policy." *Environmental and Resource Economics* 55.1 (2013): 21–46.

Monastersky, R. "Global Carbon Dioxide Levels Near Worrisome Milestone." *Nature* 497.7447 (2013): 13. http://www.nature.com/news/global-carbon-dioxide-levels-near-worrisome-milestone-1.12900.

Morris, Eric. "From Horse Power to Horsepower." *Access* 30 (2007): 2–9. http://www.uctc.net/access/30/Access%2030%20-%2002%20-%20Horse%20Power.pdf.

Morris, Errol. "The Certainty of Donald Rumsfeld." *New York Times* Opinionator, 4-part series (March 2014). http://opinionator.blogs.nytimes.com/2014/03/25/the-certainty-of-donald-rumsfeld-part-1/.

Morris, Ian. *Why the West Rules—for Now: The Patterns of History and What They Reveal about the Future*. Farrar Straus and Giroux, 2010. http://books.google.com/books?id=qNVrfoSubmIC.

Moyer, Elisabeth, Michael D. Woolley, Michael Glotter, and David A. Weisbach. "Climate Impacts on Economic Growth as Drivers of Uncertainty in the Social Cost of Carbon." *Center for Robust Decision Making on Climate and Energy Policy Working Paper* 13 (2013): 25. http://www.law.uchicago.edu/files/file/652-ejm-mdw-mjg-daw-climate-new.pdf.

Nabuurs, Gert-Jan, Marcus Lindner, Pieter J. Verkerk, Katja Gunia, Paola Deda, Roman Michalak, and Giacomo Grassi. "First Signs of Carbon Sink Saturation in European Forest Biomass." *Nature Climate Change* 3.9 (2013): 792–96. http://www.nature.com/nclimate/journal/v3/n9/full/nclimate1853.html.

"NASA Authorization Act of 2005" (Public Law No. 109–155, 119 Stat. 2895, 2005). http://www.gpo.gov/fdsys/pkg/PLAW-109publ155/pdf/PLAW-109publ155.pdf.

National Disaster Risk Reduction and Management Council. Situation Report No. 38 re Effects of Typhoon "PABLO" (BOPHA), December 25, 2012. http://www.ndrrmc.gov.ph/attachments/article/835/Update%20Sitrep%20No.%2038.pdf.

"Near-Earth Object Survey and Deflection Analysis of Alternatives." NASA, 2007. http://www.nasa.gov/pdf/171331main_NEO_report_march07.pdf.

Newell, Richard G., and William A. Pizer. "Regulating Stock Externalities under Uncertainty," *Journal of Environmental Economics and Management* 45.2 (2003): 416–32. http://www.sciencedirect.com/science/article/pii/S0095069602000165.

Nguyen B. T., J. Lehmann, J. Kinyangi, R. Smernik, S. J. Riha, and M. H. Engelhard. "Long-Term Black Carbon Dynamics in Cultivated Soil." *Biogeochemistry* 89.3 (2008): 295–308. http://link.springer.com/article/10.1007%2Fs10533-008-9220-9.

"Nigeria Restores Fuel Subsidy to Quell Nationwide Protests." *Guardian* (January 16, 2012). http://www.guardian.co.uk/world/2012/jan/16/nigeria-restores-fuel-subsidy-protests.

Nordhaus, William D. *The Climate Casino: Risk, Uncertainty, and Economics for a Warming World*. Yale University Press, 2013. http://www.amazon.com/The-Climate-Casino-Uncertainty-Economics/dp/030018977X.

Nordhaus, William D. "Economic Aspects of Global Warming in a Post-Copenhagen Environment." *Proceedings of the National Academy of Sciences* 107.26 (2010): 11721–26. http://www.pnas.org/content/107/26/11721.full.

———. "Estimates of the Social Cost of Carbon: Concepts and Results from the DICE-2013R Model and Alternative Approaches." *Journal of the Association of Environmental and Resource Economists* 1.1 (2014): 273–312. http://dx.doi.org/10.1086/676035.

———. "Optimal Greenhouse Gas Reductions and Tax Policy in the 'DICE' Model." *American Economic Review* 83.2 (1993): 313–17. http://ideas.repec.org/a/aea/aecrev/v83y1993i2p313-17.html.

———. "An Optimal Transition Path for Controlling Greenhouse Gases." *Science* 258.5086 (1992): 1315–19. http://www.sciencemag.org/content/258/5086/1315.

———. "To Slow or Not to Slow: The Economics of the Greenhouse Effect." *Economic Journal* 101.407 (1991): 920–37. http://ideas.repec.org/a/ecj/econjl/v101y1991i407p920-37.html.

Normile, Dennis. "Clues to Supertyphoon's Ferocity Found in the Western Pacific." *Science* 342.6162 (2013): 1027. http://www.sciencemag.org/content/342/6162/1027.short.

OECD. *Inventory of Estimated Budgetary Support and Tax Expenditures for Fossil Fuels 2013.* OECD Publishing, 2013. http://dx/doi.org/10.1787/9789264187610-en.

Office of Management and Budget (OMB). "Circular No. A-94 Revised" (October 29, 1992). http://www.whitehouse.gov/omb/circulars_a094.

Ogburn, Stephanie Paige. "How Media Pushed Climate Change 'Pause' into the Mainstream." *Environment and Energy Publishing* (November 4, 2013). http://www.eenews.net/stories/1059989863.

———. "What's in a Name? Would 'the Pause' by Any Other Name Help Scientists Communicate?" *Environment and Energy Publishing* (November 1, 2013). http://www.eenews.net/stories/1059989790.

Oleson, Keith W., G. B. Bonan, and J. Feddema. "Effects of White Roofs on Urban Temperature in a Global Climate Model." *Geophysical Research Letters* 37.3 (2010). http://onlinelibrary.wiley.com/doi/10.1029/2009GL042194/abstract.

Olivier, Jos, Greet Janssens-Maenhous, Marilena Muntean, and Jeroen Peters. "Trends in Global CO_2 Emissions: 2013 Report." PBL Netherlands Environmental Assessment Agency and European Commission Joint Research Center, 2013. http://edgar.jrc.ec.europa.eu/news_docs/pbl-2013-trends-in-global-co2-emissions-2013-report-1148.pdf.

"Operation Ivy." U.S. Nuclear Weapons Archive (last modified 1999). http://nuclearweaponarchive.org/Usa/Tests/Ivy.html.

Otto, F.E.L., N. Massey, G. J. Oldenborgh, R. G. Jones, and M. R. Allen. "Reconciling Two Approaches to Attribution of the 2010 Russian Heat Wave." *Geophysical Research Letters* 39.4 (2012). http://onlinelibrary.wiley.com/doi/10.1029/2011GL050422/abstract.

Pall, Pardeep, Tolu Aina, Daithi A. Stone, Peter A. Stott, Toru Nozawa, Arno G. J. Hilberts, Dag Lohmann, and Myles R. Allen. "Anthropogenic Greenhouse Gas Contribution to Flood Risk in England and Wales in Autumn 2000." *Nature* 470.7334 (2011): 382–85. http://www.nature.com/nature/journal/v470/n7334/abs/nature09762.html.

Palumbi, Stephen R., Daniel J. Barshis, Nikki Traylor-Knowles, and Rachael A. Bay. "Mechanisms of Reef Coral Resistance to Future Climate Change." *Science* 344.6186 (2014): 895–98. http://www.sciencemag.org/content/early/2014/04/23/science.1251336.abstract.

Parfit, Derek "Five Mistakes in Moral Mathematics." Chap. 3 of *Reasons and Persons*. Oxford University Press, 1986. 67–86. http://www.oxfordscholarship.com/view/10.1093/019824908X.001.0001/acprof-9780198249085.

Parris, A., P. Bromirski, V. Burkett, D. Cayan, M. Culver, J. Hall, R. Horton, K. Knuuti, R. Moss, J. Obeysekera, A. Sallenger, and J. Weiss. "Global Sea Level Rise Scenarios for the United States National Climate Assessment." National Oceanic and Atmospheric Administration Tech Memo OAR CPO (2012). http://cpo.noaa.gov/sites/cpo/Reports/2012/NOAA_SLR_r3.pdf.

Parson, Edward A. "The Big One: A Review of Richard Posner's Catastrophe: Risk and Response." *Journal of Economic Literature* 45.1 (2007): 147–64. http://www.jstor.org/discover/10.2307/27646750.

Parson, Edward A., and David W. Keith. "End the Deadlock on Governance of Geoengineering Governance." *Science* 339.6125 (2013): 1278–79. http://www.sciencemag.org/content/339/6125/1278.

Peterson, Thomas C., Peter A. Stott, and Stephanie Herring. "Explaining Extreme Events of 2011 from a Climate Perspective." *Bulletin of the American Meteorological Society* 93.7 (2012): 1041–67. http://journals.ametsoc.org/doi/abs/10.1175/BAMS-D-12-00021.1.

Pew Global Attitudes Project (June 2013). http://www.pewglobal.org/files/2013/06/Pew-Research-Center-Global-Attitudes-Project-Global-Threats-Report-FINAL-June-24-20131.pdf.

Pew Research Center / USA Today Survey (February 21 2013). http://www.people-press.org/files/legacy-pdf/02-21-13%20Political%20Release.pdf.

"Philippines: Typhoon Haiyan Situation Report No. 34." United Nations Office for the Coordination of Humanitarian Affairs (2013).

http://reliefweb.int/sites/reliefweb.int/files/resources/OCHA PhilippinesTyphoonHaiyanSitrepNo.34.28Jan2014.pdf.

Pigou, Arthur. 1920. *The Economics of Welfare*. 4th ed. Macmillan, 1932. http://www.econlib.org/library/NPDBooks/Pigou/pgEW20.html #Part II, Chapter 9.

Piketty, Thomas. *Capital in the 21st Century*. Harvard University Press, 2014. http://www.hup.harvard.edu/catalog.php?isbn=9780674430006.

Pindyck, Robert S., "Climate Change Policy: What Do the Models Tell Us?" *Journal of Economic Literature* 51.3 (2013): 860–72. http://www.aeaweb.org/articles.php?f=s&doi=10.1257/jel.51.3.860.

Pongratz, Julia, D. B. Lobell, L. Cao, and K. Caldeira. "Crop Yields in a Geoengineered Climate." *Nature Climate Change* 2.2 (2012): 101–5. http://www.nature.com/nclimate/journal/v2/n2/full/nclimate1373.html.

Posner, Richard A. *Catastrophe: Risk and Response*. Oxford University Press, 2004. http://books.google.com/books/about/Catastrophe_Risk_and_Response.html?id=SDe59lXSrY8C.

"Pressure Continues: Stocks Sink Lower under Record Volume of Liquidation." *Wall Street Journal* (October 30, 1929).

Previdi, M., B. G. Liepert, D. Peteet, J. Hansen, D. J. Beerling, A. J. Broccoli, S. Frolking et al. "Climate Sensitivity in the Anthropocene." *Quarterly Journal of the Royal Meteorological Society* 139.674 (2013): 1121–31. http://onlinelibrary.wiley.com/doi/10.1002/qj.2165/abstract.

Pun, Iam-Fei, I-I. Lin, and Min-Hui Lo. "Recent Increase in High Tropical Cyclone Heat Potential Area in the Western North Pacific Ocean." *Geophysical Research Letters* 40.17 (2013): 4680–84. http://onlinelibrary.wiley.com/doi/10.1002/grl.50548/abstract.

Rahmstorf, Stefan, and Dim Coumou. "Increase of Extreme Events in a Warming World." *Proceedings of the National Academy of Sciences* 108.44 (2011): 17905–9. http://www.pnas.org/content/108/44/17905.short.

Ramanathan, Veerabhadran, and Yan Feng. "On Avoiding Dangerous Anthropogenic Interference with the Climate System: Formidable Challenges Ahead." *Proceedings of the National Academy of Sciences* 105.38 (2008): 14245–50. http://www.pnas.org/content/105/38/14245.short.

Rau, Greg H. "CO_2 Mitigation via Capture and Chemical Conversion in Seawater." *Environmental Science and Technology* 45.3 (2010): 1088–92. http://pubs.acs.org/doi/abs/10.1021/es102671x.

Rayner, Steve, Clare Heyward, Tim Kruger, Nick Pidgeon, Catherine Redgwell, and Julian Savulescu. "The Oxford Principles." *Climatic Change* 121.3 (2013): 499–512. http://link.springer.com/article/10.1007/s10584-012-0675-2.

Reichstein, Markus, Michael Bahn, Philippe Ciais, Dorothea Frank, Miguel D. Mahecha, Sonia I. Seneviratne, Jakob Zscheischier et al. "Climate Extremes and the Carbon Cycle." *Nature* 500.7462 (2013): 287–95. http://www.nature.com/nature/journal/v500/n7462/full/nature12350.html.

"Report: The After Action Review / Lessons Learned Workshops for Typhoon Bopha Response." United Nations Office for the Coordination of Humanitarian Affairs (2013). http://reliefweb.int/sites/reliefweb.int/files/resources/Bopha%20AAR-LLR%20Report%202013_FINAL_14%20June%202013.pdf.

Revesz, Richard, and Michael Livermore. *Retaking Rationality: How Cost-Benefit Analysis Can Better Protect the Environment and Our Health*. Oxford University Press, 2008. http://www.amazon.com/Retaking-Rationality-Benefit-Analysis-Environment/dp/0195368576.

Ricke, Katharine L., M. Granger Morgan, and Myles R. Allen. "Regional Climate Response to Solar-Radiation Management." *Nature Geoscience* 3.8 (2010): 537–41. http://www.nature.com/ngeo/journal/v3/n8/full/ngeo915.html.

Rignot, E., J. Mouginot, M. Morlighem, H. Seroussi, and B. Scheuchl. "Widespread, Rapid Grounding Line Retreat of Pine Island, Thwaites, Smith and Kohler Glaciers, West Antarctica from 1992 to 2011." *Geophysical Research Letters* 41.10 (2014): 3502–9. http://onlinelibrary.wiley.com/doi/10.1002/2014GL060140/abstract.

Risky Business Project. *Risky Business: The Economic Risks of Climate Change in the United States*. 2014. http://riskybusiness.org.

Robine, Jean-Marie, Siu Lan K. Cheung, Sophie Le Roy, Herman Van Oyen, Claire Griffiths, Jean-Pierre Michel, François Richard Herrmann. "Death Toll Exceeded 70,000 in Europe during the Summer of 2003." *Comptes rendus biologies* 331.2 (2008): 171–78. http://www.sciencedirect.com/science/article/pii/S1631069107003770.

Robock, Alan. "20 Reasons Why Geoengineering May Be a Bad Idea." *Bulletin of the Atomic Scientists* 64.2 (2008): 14–18, 59. http://www.atmos.washington.edu/academics/classes/2012Q1/111/20Reasons.pdf.

———. "Is Geoengineering Research Ethical?" *Peace and Security* 4 (2012): 226–29. http://climate.envsci.rutgers.edu/pdf/GeoResearchEthics.pdf.

Robock, Alan, L. Oman, and G. L. Stenchikov. "Regional Climate Responses to Geoengineering with Tropical and Arctic SO_2 Injections." *Journal of Geophysical Research* 113.D16 (2008): D16101. http://onlinelibrary.wiley.com/doi/10.1029/2008JD010050/abstract.

Roe, Gerard. "Costing the Earth: A Numbers Game or a Moral Imperative?" *Weather, Climate, and Society* 5.4 (2013): 378–80. http://journals.ametsoc.org/doi/abs/10.1175/WCAS-D-12-00047.1.

Roe, Gerard H., and Yoram Bauman. "Climate Sensitivity: Should the Climate Tail Wag the Policy Dog?" *Climatic Change* 117.4 (2013): 647–62. http://link.springer.com/article/10.1007/s10584-012-0582-6.

Rosenthal, Elisabeth. "Your Biggest Carbon Sin May Be Air Travel." *New York Times* (January 27, 2013): SR4. http://www.nytimes.com/2013/01/27/sunday-review/the-biggest-carbon-sin-air-travel.html.

Rosenzweig, C. and W. Solecki, eds. "Climate Risk Information 2013: Observations, Climate Change Projections, and Maps." New York City Panel on Climate Change (June 2013). http://www.nyc.gov/html/planyc2030/downloads/pdf/npcc_climate_risk_information_2013_report.pdf.

Roston, Eric. *The Carbon Age: How Life's Core Element Has Become Civilization's Greatest Threat*. Bloomsbury Publishing USA, 2009. http://www.ericroston.com/.

Rottenberg, Dan. *In the Kingdom of Coal*. Routledge, 2003. http://books.google.com/books/about/In_the_Kingdom_of_Coal.html?id=VL8YWx2X8asC.

Rowley, Rex J., John C. Kostelnick, David Braaten, Xingong Li, and Joshua Meisel. "Risk of Rising Sea Level to Population and Land Area." *Eos, Transactions American Geophysical Union* 88.9 (2007): 105–7. http://onlinelibrary.wiley.com/doi/10.1029/2007EO090001/abstract.

Royal Society. "Geoengineering the Climate: Science, Governance and Uncertainty" (September 2009). http://royalsociety.org/uploadedFiles/Royal_Society_Content/policy/publications/2009/8693.pdf.

Rumsfeld, Donald. "Press Conference at NATO Headquarters." Brussels, Belgium (June 6, 2002). http://www.defense.gov/transcripts/transcript.aspx?transcriptid=3490.

Rybczynski, Natalia, John C. Gosse, C. Richard Harington, Roy A. Wogelius, Alan J. Hidy, and Mike Buckley. "Mid-Pliocene Warm-Period Deposits in the High Arctic Yield Insight into Camel Evolution." *Nature Communications* 4 (2013): 1550. http://www.nature.com/ncomms/journal/v4/n3/full/ncomms2516.html.

Salter, Stephen, Graham Sortino, and John Latham, "Sea-Going Hardware for the Cloud Albedo Method of Reversing Global Warming." *Philosophical Transactions of the Royal Society* 366.1882 (2008): 3989–4006. http://rsta.royalsocietypublishing.org/content/366/1882/3989.full.

Samuelson, William, and Richard Zeckhauser. "Status Quo Bias in Decision Making." *Journal of Risk and Uncertainty* 1.1 (1988): 7–59. http://dtserv2.compsy.uni-jena.de/__C125757B00364C53.nsf/0/F0CC3CAE039C8B42C125757B00473C77/$FILE/samuelson_zeckhauser_1988.pdf.

Sandel, Michael J. *Justice*: *What's the Right Thing to Do*? Farrar Strauss and Giroux, 2009. http://www.justiceharvard.org/.

———. "Market Reasoning as Moral Reasoning: Why Economists Should Re-engage with Political Philosophy." *Journal of Economic Perspectives* 27.4 (2013): 121–40. http://pubs.aeaweb.org/doi/pdfplus/10.1257/jep.27.4.121.

Sandsmark, Maria, and Haakon Vennemo, "A Portfolio Approach to Climate Investments: CAPM and Endogenous Risk." *Environmental and Resource Economics* 37.4 (2007): 681–95. http://link.springer.com/article/10.1007/s10640-006-9049-4.

Schelling, Thomas, "The Economic Diplomacy of Geoengineering." *Climatic Change* 33.3 (1996): 303–7. http://link.springer.com/article/10.1007%2FBF00142578.

Schlosser, Eric. *Command and Control*. Penguin, 2013.

Schmidt, Gavin, and Stefan Rahmstorf. "11°C Warming, Climate Crisis in 10 Years?" RealClimate.org (January 29, 2005). http://www.realclimate.org/index.php/archives/2005/01/climatepredictionnet-climate-challenges-and-climate-sensitivity/.

Schneider, Stephen H. *Science as a Contact Sport*. National Geographic Society, 2009. http://www.amazon.com/Science-Contact-Sport-Inside-Climate/dp/1426205406.

Self, Stephen, Jing-Xia Zhao, Rick E. Holasek, Ronnie C. Torres, and Alan J. King. "The Atmospheric Impact of the 1991 Mount Pinatubo Eruption." U.S. Geological Survey, 1999. http://pubs.usgs.gov/pinatubo/self/index.html.

Shepherd, Andrew, Erik R. Ivins, A. Geruo, Valentina R. Barletta, Mike J. Bentley, Srinivas Bettadpur, Kate H. Briggs et al. "A Reconciled Estimate of Ice-Sheet Mass Balance." *Science* 338.6111 (2012): 1183–89. http://www.sciencemag.org/content/338/6111/1183.

Sherwood, Steven C., Sandrine Bony, and Jean-Louis Dufresne. "Spread in Model Climate Sensitivity Traced to Atmospheric Convective Mixing." *Nature* 505.7481 (2014): 37–42. http://www.nature.com/nature/journal/v505/n7481/full/nature12829.html.

Shoemaker, Julie K., and Daniel P. Schrag. "The Danger of Overvaluing Methane's Influence on Future Climate Change." *Climatic Change* 120.4 (2013): 903–14. http://link.springer.com/article/10.1007/s10584-013-0861-x.

Silver, Nate. "Crunching the Risk Numbers." *Wall Street Journal* (January 8, 2010). http://online.wsj.com/news/articles/SB10001424052748703481004574646963713065 11.

Socolow, Robert. "Truths We Must Tell Ourselves to Manage Climate Change." *Vanderbilt Law Review* 65.6 (2012): 1455–78. http://www.vanderbiltlawreview.org/content/articles/2012/11/Socolow_-65_Vand_L_Rev_1455.pdf.

Solomon, Pierrehumbert, Damon Matthews, John S. Daniel, and Pierre Friedlingstein. "Atmospheric Composition, Irreversible Climate Change, and Mitigation Policy." In *Climate Science for Serving Society*. Springer Netherlands, 2013. 415–36. http://link.springer.com/chapter/10.1007/978-94-007-6692-1_15.

Solomon, Susan, Gian-Kasper Plattner, Reto Knutti, and Pierre Friedlingstein. "Irreversible Climate Change Due to Carbon Dioxide Emissions." *Proceedings of the National Academy of Sciences* 106.6 (2009): 1704–9. http://www.pnas.org/content/early/2009/01/28/0812721106.abstract.

Specter, Michael. "The First Geo-Vigilante." *New Yorker* (October 2012). http://www.newyorker.com/online/blogs/newsdesk/2012/10/the-first-geo-vigilante.html.

"Statistic Data on the German Solar Power (Photovoltaic) Industry." German Solar Industry Association (BSW-Solar) (June 2013). http://www.solarwirtschaft.de/fileadmin/media/pdf/2013_2_BSW-Solar_fact_sheet_solar_power.pdf.

Stenchikov, Georgiy L., Ingo Kirchner, Alan Robock, Hans-F. Graf, Juan Carlos Antuna, R. G. Grainger, Alyn Lambert, and Larry Thomason. "Radiative Forcing from the 1991 Mount Pinatubo Volcanic Eruption." *Journal of Geophysical Research: Atmospheres (1984–2012)* 103.D12 (1998): 13837–57. http://onlinelibrary.wiley.com/doi/10.1029/98JD00693/abstract.

Stephens, Phillip. "Major Puts ERM Membership on Indefinite Hold." *Financial Times* (September 25, 1992).

Sterman, John D. "Risk Communication on Climate: Mental Models and Mass Balance." *Science* 322.5901 (2008): 532–33. http://www.sciencemag.org/content/322/5901/532.summary.

Stern, Nicholas. "The Structure of Economic Modeling of the Potential Impacts of Climate Change: Grafting Gross Underestimation of Risk onto Already Narrow Science Models." *Journal of Economic Literature* 51.3 (2013): 838–59. http://www.aeaweb.org/articles.php?doi=10.1257/jel.51.3.838.

Sterner, Thomas, ed. *Fuel Taxes and the Poor: The Distributional Consequences of Gasoline Taxation and Their Implications for Climate Policy*. RFF Press, 2011. http://www.routledge.com/books/details/9781617260926/.

Sterner, Thomas, and U. Martin Persson. "An Even Sterner Review: Introducing Relative Prices into the Discounting Debate." *Review of Environmental Economics and Policy* 2.1 (2008): 61–76. http://reep.oxfordjournals.org/content/2/1/61.short.

Stocker, Thomas F. "The Closing Door of Climate Targets." *Science* 339.6117 (2013): 280–82. http://www.sciencemag.org/content/339/6117/280.full?sid=a0ad9885-1715-4bff-a27f-54d5f68c15e2#ref-2.

Stommel, Henry M. *Volcano Weather: The Story of 1816, the Year without a Summer*. Seven Seas Press, 1983.

Stothers, Richard B. "The Great Tambora Eruption in 1815 and Its Aftermath." *Science* 224.4654 (1984): 1191–98. http://www.sciencemag.org/content/224/4654/1191.short.

Stott, Peter A., Myles Allen, Nikolaos Christidis, Randall M. Dole, Martin Hoerling, Chris Huntingford, Pardeep Pall, Judith Perlwitz, and Dáithí Stone. "Attribution of Weather and Climate-Related Events." In *Climate Science for Serving Society*, edited by Ghassem R. Asrar and James W. Hurrell. Netherlands: Springer, 2013. 307–37. http://link.springer.com/chapter/10.1007%2F978-94-007-6692-1_12.

Stott, Peter A., Dáithí Stone, and Myles Allen. "Human Contribution to the European Heatwave of 2003." *Nature* 432.7017 (2004): 610–14. http://www.nature.com/nature/journal/v432/n7017/abs/nature03089.html.

Strong, Aaron, Sallie Chisholm, Charles Miller, and John Cullen. "Ocean Fertilization: Time to Move on." *Nature* 461.7262 (2009): 347–48. http://www.nature.com/nature/journal/v461/n7262/full/461347a.html.

Summers, Lawrence H. "Comments on Richard Zeckhauser's Investing in the Unknown and Unknowable." *Capitalism and Society* 1.2 (September 2006). http://dx.doi.org/10.2202/1932-0213.1012.

Sunstein, Cass R. "Of Montreal and Kyoto: A Tale of Two Protocols." *Harvard Environmental Law Review* 31 (2007): 1. http://heinonline.org/HOL/LandingPage?collection=journals&handle=hein.journals/helr31&div=5&id=&page=.

———. *Worst-Case Scenarios*. Harvard University Press, 2007. http://www.hup.harvard.edu/catalog.php?isbn=9780674032514.

Survey Findings on Energy and the Economy. Institute for Energy Research, July 12 2013. http://www.instituteforenergyresearch.org/wp-content/uploads/2013/07/IER-National-Survey.-Key-Findings.pdf.

Taleb, Nassim Nicholas. *The Black Swan: The Impact of the Highly Improbable Fragility*. Random House, 2010. http://www.fooledbyrandomness.com.

Talke, S. A., P. Orton, and D. A. Jay. "Increasing Storm Tides in New York Harbor, 1844–2013." *Geophysical Research Letters* 41.9 (2014): 3149–55. http://onlinelibrary.wiley.com/doi/10.1002/2014GL059574/abstract.

"Technical Update of the Social Cost of Carbon for Regulatory Impact Analysis under Executive Order 12866." United States Government

Interagency Working Group on Social Cost of Carbon (November 1, 2013). http://www.whitehouse.gov/sites/default/files/omb/assets/inforeg/technical-update-social-cost-of-carbon-for-regulator-impact-analysis.pdf.

Thomas, E. "Biogeography of the Late Paleocene Benthic Foraminiferal Extinction." In *Late Paleocene–Early Eocene Climatic and Biotic Events in the Marine and Terrestrial Records*, edited by M. P. Aubry, S. C. Lucas, and W. A. Berggren. Columbia University Press, 1998. 214–43. http://books.google.com/books?hl=en&lr=&id=BR-zAQAAQBAJ&oi.

Thomson, Judith Jarvis. "The Trolley Problem." *Yale Law Journal* 94.6 (1985): 1395–415. http://www.jstor.org/stable/796133.

Thøgersen, John, and Tom Crompton. "Simple and Painless? The Limitations of Spillover in Environmental Campaigning." WWF United Kingdom (2009). http://www.wwf.org.uk/research_centre/research_centre_results.cfm?uNewsID=2728.

"Threat of Space Objects Demands International Coordination, UN Team Says." UN News Center (February 2013). http://www.un.org/apps/news/story.asp?NewsID=44186&Cr=outer+space&Cr1=#.UnAt3JQ-vvA.

Titmuss, Richard M. *The Gift Relationship*. Allen and Unwin, 1970.

"Tobacco Shares Fall on Australian Packaging Rule." *Telegraph* (August 15, 2013). http://www.telegraph.co.uk/finance/newsbysector/retailandconsumer/9476621/Tobacco-shares-fall-on-Australian-packaging-ruling.html.

Tol, Richard S. J. "Correction and Update: The Economic Effects of Climate Change." *Journal of Economic Perspectives* 28.2 (2014): 221–26. http://pubs.aeaweb.org/doi/pdfplus/10.1257/jep.28.2.221.

———. "The Economic Impact of Climate Change in the 20th and 21st Centuries." *Climatic Change* 117.4 (2013): 795–808. http://link.springer.com/article/10.1007%2Fs10584-012-0613-3.

———. "Estimates of the Damage Costs of Climate Change—Part I: Benchmark Estimates." *Environmental and Resource Economics* 21.1 (2002): 47–73. http://link.springer.com/article/10.1023%2FA%3A1014500930521.

Tollefson, Jeff. "Hurricane Sandy Spins Up Climate Discussion." *Nature: News* (October 30, 2012). http://www.nature.com/news/hurricane-sandy-spins-up-climate-discussion-1.11706.

———. "Ocean-Fertilization Project off Canada Sparks Furore." *Nature* 490.7421 (2012): 458–59. http://www.nature.com/news/ocean-fertilization-project-off-canada-sparks-furore-1.11631.

Trenberth, Kevin E., and Aiguo Dai. "Effects of Mount Pinatubo Volcanic Eruption on the Hydrological Cycle as an Analog of Geoengineering."

Geophysical Research Letters 34: L15702 (2007). http://onlinelibrary.wiley.com/doi/10.1029/2007GL030524/abstract.

Tyndall, John. "XXIII. On the Absorption and Radiation of Heat by Gases and Vapours, and on the Physical Connexion of Radiation, Absorption, and Conduction—the Bakerian Lecture." *London, Edinburgh, and Dublin Philosophical Magazine and Journal of Science* 22.146 (1861): 169–94. http://www.gps.caltech.edu/~vijay/Papers/Spectroscopy/tyndall-1861.pdf.

United Nations. *Our Common Future*. Report of the World Commission on Environment and Development (1987). http://www.un-documents.net/our-common-future.pdf.

U.S. Department of Defense. "Quadrennial Defense Review Report." (February 2010). http://www.defense.gov/qdr/qdr%20as%20of%2026jan10%200700.pdf.

U.S. Environmental Protection Agency. "Climate Change Indicators in the United States: U.S. and Global Temperature." 2012. http://www.epa.gov/climatechange/science/indicators/weather-climate/temperature.html.

———. "Drinking Water Contaminants" (last updated June 2013). http://water.epa.gov/drink/contaminants/.

———. "Overview of Greenhouse Gases: Carbon Dioxide Emissions." http://www.epa.gov/climatechange/ghgemissions/gases/co2.html.

U.S. Global Change Research Program. "Climate Change Impacts in the United States." 2014. http://nca2014.globalchange.gov/.

U.S. Supreme Court. Global-Tech Appliances, Inc., et al. v. SEB S.a. 563 No. 10–6 (May 31, 2011). http://www.supremecourt.gov/opinions/10pdf/10-6.pdf.

van Benthem, Arthur, Kenneth Gillingham, and James Sweeney. "Learning-by-Doing and the Optimal Solar Policy in California." *Energy Journal* 29.3 (2008): 131–52. http://ideas.repec.org/a/aen/journl/2008v29-03-a07.html.

van den Bergh, J.C.J.M., and W.J.W. Botzen. "A Lower Bound to the Social Cost of CO_2 Emissions." *Nature Climate Change* 4.4 (2014): 253–58. http://www.nature.com/nclimate/journal/v4/n4/full/nclimate2135.html.

Viscusi, W. Kip, and Joseph E. Aldy. "The Value of a Statistical Life: A Critical Review of Market Estimates throughout the World." *Journal of Risk and Uncertainty* 27.1 (2003): 5–76. http://www.nber.org/papers/w9487.

Vivid Economics. "The Implicit Price of Carbon in the Electricity Sector of Six Major Economies." Report Prepared for the Climate Institute (October 2010). http://www.vivideconomics.com/docs/Vivid%20Econ%20Implicit%20Carbon%20Prices.pdf.

Voosen, Paul. "Provoked Scientists Try to Explain Lag in Global Warming." Environment and Energy Publishing, 2011. http://www.eenews.net/stories/1059955427.

Wagner, Gernot. *But Will the Planet Notice? How Smart Economics Can Save the World*. Hill and Wang, 2011. http://www.gwagner.com/planet.

———. "Going Green but Getting Nowhere." *New York Times* (September 8, 2011). http://www.nytimes.com/2011/09/08/opinion/going-green-but-getting-nowhere.html.

———. "Naomi Klein Is Half Right: Distorted Markets Are the Real Problem." Grist.org (March 14, 2012). http://grist.org/climate-change/naomi-klein-is-half-right-distorted-markets-are-the-real-problem/.

Wagner, Gernot, and Martin L. Weitzman. "Playing God." Foreign Policy.com (October 24, 2012). http://www.foreignpolicy.com/articles/2012/10/22/playing_god.

Wagner, Gernot, and Richard J. Zeckhauser. "Climate Policy: Hard Problem, Soft Thinking." *Climatic Change* 110.3–4 (2012): 507–21. http://link.springer.com/article/10.1007%2Fs10584-011-0067-z.

Walter, K. M., S. A. Zimov, Jeff P. Chanton, D. Verbyla, and F. S. Chapin III. "Methane Bubbling from Siberian Thaw Lakes as a Positive Feedback to Climate Warming." *Nature* 443.7107 (2006): 71–75. http://www.nature.com/nature/journal/v443/n7107/abs/nature05040.html.

Weaver, R. Kent. "The Politics of Blame Avoidance." *Journal of Public Policy* 6.4 (1986): 371–98. http://dx.doi.org/10.1017/S0143814X00004219.

Weitzman, Martin L. "Can Negotiating a Uniform Carbon Price Help to Internalize the Global Warming Externality?" NBER Working Paper No. 19644 (November 2013), forthcoming in the *Journal of the Association of Environmental and Resource Economists*. http://www.nber.org/papers/w19644.pdf.

———. "Fat-Tailed Uncertainty in the Economics of Catastrophic Climate Change." *Review of Environmental Economics and Policy* 5.2 (2011): 275–92. http://scholar.harvard.edu/weitzman/publications/fat-tailed-uncertainty-economics-catastrophic-climate-change-0.

———. "Fat Tails and the Social Cost of Carbon." *American Economic Review: Papers and Proceedings* 104.5 (2014): 544–46. http://dx.doi.org/10.1257/aer.104.5.544.

———. "Gamma discounting." *American Economic Review* 91.1 (2001): 260–71. http://scholar.harvard.edu/files/weitzman/files/gamma_discounting.pdf.

———. "GHG Targets as Insurance against Catastrophic Climate Damages." *Journal of Public Economic Theory* 14.2 (2012): 221–44. http://scholar.harvard.edu/weitzman/publications/ghg-targets-insurance-against-catastrophic-climate-damages-0.

———. "The Geoengineered Planet." In *In 100 Years*, edited by Ignacio Palacios-Huerta. MIT Press, 2013. 145–63. http://scholar.harvard.edu/weitzman/publications/one-hundred-years-chapter-10-geoengineered-planet.

———. "On Modeling and Interpreting the Economics of Catastrophic Climate Change." *Review of Economics and Statistics* 91.1 (2009):1–19. http://scholar.harvard.edu/weitzman/publications/modeling-and-interpreting-economics-catastrophic-climate-change.

———. "Prices vs. Quantities." *Review of Economic Studies* 41.4 (1974): 477–91. http://www.jstor.org/discover/10.2307/2296698.

———. "Recombinant Growth." *Quarterly Journal of Economics* 113.2 (1998): 331–60. http://qje.oxfordjournals.org/content/113/2/331.short.

———. "A Review of the Stern Review on the Economics of Climate Change." *Journal of Economic Literature* 45.3 (2007): 703–24. http://www.aeaweb.org/articles.php?doi=10.1257/jel.45.3.703.

———. "Subjective Expectations and Asset-Return Puzzles." *American Economic Review* 97.4 (2007): 1102–30. http://www.jstor.org/discover/10.2307/30034086.

———. "A Voting Architecture for the Governance of Free-Driver Externalities, with Application to Geoengineering." *Scandinavian Journal of Economics*, forthcoming. http://scholar.harvard.edu/weitzman/publications/voting-architecture-governance-free-driver-externalities-application.

———. "What Is the 'Damages Function' for Global Warming—and What Difference Might it Make?" *Climate Change Economics* 1.1(2010): 57–69. http://scholar.harvard.edu/weitzman/publications/what-damages-function%E2%80%9F-global-warming-%E2%80%93-and-what-difference-might-it-make.

"What We Know: The Realities, Risks and Response to Climate Change." American Association for the Advancement of Science (2014). http://whatweknow.aaas.org/wp-content/uploads/2014/03/AAAS-What-We-Know.pdf.

White House Press Release. August 6, 1945, Harry S. Truman Library. https://www.trumanlibrary.org/whistlestop/study_collections/bomb/large/documents/index.php?documentdate=1945-08-06&documentid=59&studycollectionid=abomb&pagenumber=1.

Willis, Margaret M., and Juliet B. Schor. "Does Changing a Light Bulb Lead to Changing the World? Political Action and the Conscious Consumer." *Annals of the American Academy of Political and Social Science* 644.1 (2012): 160–90. http://ann.sagepub.com/content/644/1/160.abstract.

Wood, Graeme. "Re-engineering the Earth." *Atlantic* (June 2009). http://www.theatlantic.com/magazine/archive/2009/07/re-engineering-the-earth/307552/.

"World Energy Outlook 2013." International Energy Agency (2013). http://www.worldenergyoutlook.org/publications/weo-2013/.

"World Energy Outlook 2014." International Energy Agency (2014). http://www.worldenergyoutlook.org/publications/weo-2014/.

"The World of Civil Aviation: Facts and Figures." International Civil Aviation Organization. http://www.icao.int/sustainability/Pages/Facts Figures.aspx.

World Resource Institute (WRI). Climate Analysis Indicators Tool. http://cait.wri.org.

Yienger, James J., Meredith Galanter, Tracey A. Holloway, Mahesh J. Phadnis, Sarath K. Guttikunda, Gregory R. Carmichael, Waller J. Moxim, and Hiram Levy II. "The Episodic Nature of Air Pollution Transport from Asia to North America." *Journal of Geophysical Research* 105.D22 (2000): 26931–45. http://onlinelibrary.wiley.com/doi/10.1029/2000JD900309/abstract.

Zeckhauser, Richard J. "Investing in the Unknown and Unknowable." *Capitalism and Society* 1.2 (2006). http://www.hks.harvard.edu/fs/rzeckhau/InvestinginUnknownandUnknowable.pdf.

Zweig, Jason. "What History Tells Us about the Market." *Wall Street Journal* (October 11, 2008). http://online.wsj.com/news/articles/SB122368241652024977.

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