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BOOK REVIEW

# Hot, it's not: Reflections on *Cool It*, by Bjorn Lomborg

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Polar bears are good swimmers. A picture of a polar bear swimming in open water does not prove that the bear is in imminent danger of drowning.

The overnight freezing portrayed in the movie *The Day After Tomorrow* is unrealistic. Climate change could not literally happen at that speed.

Ambient temperature is just one of the factors that influence the spread of malaria. Lowering carbon emissions in order to limit temperature increases is not the fastest or most cost effective way to combat malaria.

These are three of the things that Bjorn Lomborg wants you to know about climate change. All three are true. All three are responses to mass media oversimplifications of the threat of climate change. Such oversimplification is an important problem to address if you agree with Lomborg's premise that the world is in danger of exaggerating the importance of climate change and doing too much to combat it.

If he had confined himself to actual examples of oversimplification and exaggeration in climate change rhetoric, Lomborg could have written a short, useful article – perhaps making the point that it is unhelpful and unnecessary to overstate the case, since the real problems of climate change are serious enough. Unfortunately, Lomborg did not write that article, but instead stretched his story into a book length claim that climate change is only a moderately serious problem, while the proposed remedies are all prohibitively expensive. Many other problems, in his view, are both more urgent and cheaper to solve.

Lomborg has written on these themes before. In *The Skeptical Environmentalist* (Lomborg 2001), he attempted an across-the-board challenge to the conventional wisdom of impending environmental crisis, including a sweeping and unpersuasive critique of the

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IPCC analysis of climate change. Numerous responses by scientists appeared, critiquing and correcting the treatment of environmental science throughout *The Skeptical Environmentalist*.

Lomborg then organized the so-called "Copenhagen Consensus," a panel of eight economists who evaluated other economists' cost–benefit analyses of priorities for global development (Lomborg 2004). Climate change fared particularly badly in the final Copenhagen Consensus rankings, classified as the lowest priority among the issues under consideration.

In his latest book, Lomborg tackles climate change again, starting with the same attitude and reaching the same conclusion. Climate change, for Lomborg, is a problem caused at least in part by human activity, but it is not nearly as serious as environmental "extremists" would have us believe. Sharply reducing emissions now, he thinks, would be horribly expensive, as shown by his estimates of the huge economic losses resulting from the Kyoto Protocol. Meanwhile, as the "Consensus" claimed, there are other, more immediate problems which can be addressed more cost effectively. Ignoring climate change is therefore evidence of concern for future generations:

> I hope that in forty years we will not have to tell our kids that we went in for a long series of essentially unsuccessful command-and-control Kyotos that had little or no effect on the climate but left them poorer and less able to deal with the problems of the future (159).

A comprehensive response to the treatment of climate science and economics in *Cool It* would require a very long essay. This review focuses on four specific areas: questions of accuracy, bias, and authority; the relationship between temperature and mortality; cost–benefit analysis of climate change vs. other priorities; and Lomborg's understanding of economics. The conclusion suggests a better approach to the economics of climate change.

## 1 Who can you trust?

As in his previous books, Lomborg (2007) adopts a voice of authority in *Cool It.* He offers a definitive-sounding explanation of the climate problem for a nontechnical audience, identifies and summarizes recent research, and tells his readers who to trust and who to doubt. This claim of authority fails both because the book is riddled with small inaccuracies, and because it displays a pervasive bias in its coverage and evaluations of climate issues.

To begin with, Lomborg has a weak grasp of some of the essential details and commits elementary mistakes, with little or no citation of sources that would explain his results. These may seem like small points, but they undermine the book's claim to provide precise, authoritative evaluations throughout the fields of climate science and economics. Early in *Cool It*, Lomborg says

> In its "standard" future scenario, the IPCC predicts that the global temperature in 2100 will have risen on average 4.7°F from the current range (11).

There is of course no such thing as one standard IPCC scenario; rather, a range of scenarios, none of them privileged above the others, describe alternate possible futures. In the notes at the back of the book, Lomborg explains that the standard he is referring to is "A1B, described as the business-as-usual scenario" (169). All of the major IPCC scenarios, however, describe business-as-usual projections under varying assumptions about the

world. Lomborg cites just one source for his mistaken belief about the unique status of A1B. That source, a technical article on climate modeling, never mentions A1B, and provides no support for Lomborg's view.

In discussing the impact of carbon taxes, Lomborg says

> ...the total present-day cost for a permanent one-dollar [per ton] $CO_2$ tax is estimated at more than $11 billion. So we might want to think twice about cranking up the knob to a thirty-dollar $CO_2$ tax, which will cost almost $7 trillion (29).

Why should a $30 tax cost hundreds of times as much as a $1 tax? If this is not a mistake, it is badly in need of explanation. The notes to this passage contain no hint as to sources, offering just one short sentence: "This is about $390 million per year" (174). That note *could* mean that in some unnamed model, a $1 tax imposes costs of $390 million a year, which would become $11 billion when extended for 28 years. If, in that model, a $30 tax imposes annual costs 30 times as large as the $1 tax, then the higher tax would lead to a total cost of $7 trillion in about 600 years, an unusually long period of time for evaluating a tax policy.

Even more opaque is page 68, which presents many numerical forecasts of particular climate impacts; there are no notes at all for that page, and again no indication of the source of the forecasts. And in some cases, the separation between main text and notes in the back of the book seems almost intentionally misleading. At one point the text says, "We will lose very little dry land to sea-level rise" (69). The notes to that passage say, "Notice that the numbers presented are for loss of dry land, whereas up to 18% of global wetlands will be lost" (182).

In addition to the inaccuracies and missing citations, *Cool It* presents a biased and incomplete picture of climate science. The book appears concerned with documenting its completeness: the 164 pages of text are supported by 34 pages of notes and a 42 page bibliography with more than 500 entries. The bibliographic entries, however, include numerous news stories, non-academic websites, standard government reports and data sources, and articles from the *Encyclopedia Britannica*, as well as citations to the scientific and economic literature. And the academic sources that are cited display a persistent slant toward climate skepticism and inaction.

Table 1 presents the number of citations of selected authors. Lomborg has multiple citations to several well-known climate skeptics, but none to the work of many of the best-known climate scientists. While stating in the text that there is no consensus on the relationship between hurricanes and climate change, Lomborg cites 11 works by Roger Pielke Jr., a leading figure on one side of the debate, and none from Kerry Emanuel, a leading scientist on the other side. A similar bias appears in the treatment of economics, heavily favoring those whose analyses call for doing very little, while ignoring those whose analyses support doing a lot about climate change. This one-sided bibliography refutes Lomborg's claim to provide an authoritative summary of the state of knowledge about climate change.

## 2 Is global warming good for your health?

Most of the distortions of climate science by the climate skeptics have been repeated, and answered, often enough; web sites such as realclimate.org provide refutations to many of the most common skeptical arguments. A less familiar argument highlighted in *Cool It*, however, may call for some discussion: the claim that the early stages of global warming

**Table 1** Lomborg's bibliography: frequency of citation for selected authors

| Works cited | Author | Works cited | Author |
|---|---|---|---|
| Well-known climate skeptics | | Well-known climate scientists | |
| 4 | Indur Goklany | 0 | James Hansen |
| 2 | Richard Lindzen | 0 | John Holdren |
| 4 | Patrick Michaels | 0 | John Houghton |
| | | 0 | James McCarthy |
| | | 0 | Stephen Schneider |
| Leading scientist skeptical of link between hurricanes and climate change | | Leading scientist whose work supports link between hurricanes and climate change | |
| 11 | Roger Pielke Jr. | 0 | Kerry Emanuel |
| Economists whose work supports slow, small-scale responses to climate change | | Economists whose work supports rapid, large-scale responses to climate change | |
| 2 | Richard Mendelsohn | 0 | Terry Barker |
| 11 | William Nordhaus | 0 | William Cline |
| 1 | Robert Stavins | 0 | Stephen DeCanio |
| 13 | Richard Tol | 0 | Chris Hope |
| 4 | Gary Yohe | 0 | Richard Howarth |
| | | 0 | Claudia Kemfert |

Two works co-authored by Tol and Yohe are counted once under each author, as is one work co-authored by Goklany and Lindzen.

will cause large reductions in mortality. The world has focused too much, Lomborg believes, on heat related deaths, which can be prevented with air conditioning, and too little on what he sees as the much greater problem of cold related deaths.

As many researchers have observed, death rates are sensitive to short-term temperature fluctuations, particularly the rates of death from cardiovascular and respiratory diseases in people over 65. In most studies, a graph of death rates versus daily temperatures is V-shaped, with higher daily mortality at either very cold or very hot temperatures. The temperature at the point of the V is the "minimum mortality temperature," or MMT, as shown in Fig. 1. It generally falls within the range of local temperatures, closer to the summer than the winter average. Moreover, as sketched in Fig. 1, the left hand (cold) side of the V is typically steeper than the right hand (hot) side; that is, cold-related deaths change more than heat-related deaths per degree of temperature change. Note that this entire

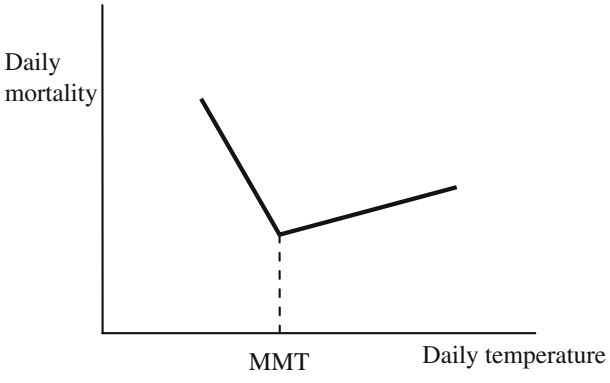


**Fig. 1** Daily mortality vs. temperature

discussion excludes extreme heat waves and cold waves; it is focused solely on the relationship between mortality and normal, short-run temperature fluctuations.

If the relationship shown in Fig. 1 remained fixed as temperatures uniformly increased, the result would be a decline in death rates due to warming. As the range of annual temperatures increased, or shifted to the right, the reduction in cold-related deaths would be faster than the rise in heat-related deaths. And that is exactly what Lomborg claims: his selective reading of the academic literature, including a study which he calls "the first complete survey for the world" (38), implies that there will be a large net decrease in deaths due to warming.

There are, however, at least three reasons to doubt that optimistic conclusion. First, as temperatures rise, the relationship in Fig. 1 only implies a reduction in mortality if the MMT does not adjust to warming – or until the adjustment occurs. If the MMT rises at the same rate as average temperatures, Fig. 1 implies that there is no effect of warming on mortality. And all the evidence, including some cited by Lomborg, suggests that people adapt to changing temperatures. A study of temperature and mortality in 11 eastern US cities found a V-shaped relationship resembling Fig. 1 in 10 of the 11 cases (Curriero et al. 2002). The MMT was almost perfectly correlated with the local average temperature, and was 9°C (16°F) warmer in Miami than in Chicago. Cities along the East Coast fell between these extremes, with MMTs rising steadily as one moves south.

This pattern provides strong support for rapid adaptation to prevailing temperatures. The populations of Miami, Chicago, and points in between are not genetically or otherwise distinct; migration from one city to another is quite common. A significant number of people from colder northern areas retire to Florida, and presumably account for many of the temperature-related deaths in Florida. If the people who move were slow to adapt to the prevailing temperatures and MMTs of their new communities, then intercity migration would lead to regression toward the mean MMT throughout the USA. Since we do not observe this pattern, adaptation must be rapid.

A second problem stems from the implicit assumption that warming will be more or less uniform throughout the year. This assumption is challenged by a recent study which looks at county-level US historical data on mortality and temperature, and at corresponding county-level temperature projections for the end of this century (Deschênes and Greenstone 2007). The study projects that warming by an average of just over 3°C will produce a small, statistically insignificant, *increase* in mortality. A principal reason for this result is that the study's detailed temperature projections show that this century's warming will bring an increase in very hot days, but almost no change in very cold days.[1] Rather, some of the formerly comfortable, low-mortality, medium temperature days will be replaced by hotter days.

A final problem with the alleged health benefits of warming is that some of the academic literature which Lomborg relies on has made arbitrary and unexplained changes to the observed empirical relationships. Elizabeth Stanton and I document this problem in our reply to Bosello et al. (2006), the article Lomborg calls "the first complete survey for the world" (Ackerman and Stanton 2008). The academic basis for the projected decline in mortality begins with a literature review which finds V-shaped temperature–mortality relationships for many locations, and makes regional projections of the effects of warming on mortality. That review implicitly assumes uniform warming throughout the year and no adaptation, and explicitly excludes analysis of extreme events such as heat waves (Martens

[1] The study uses projections from the Hadley 3 and CCSM 3 models.

1998). In a subsequent study, Richard Tol, the economist who appears 13 times in Lomborg's bibliography, uses Martens' literature review as a basis for projecting worldwide mortality changes from warming, adding the arbitrary assumption that there are no heat-related deaths from cardiovascular disease in rural areas (Tol 2002). Tol is also a co-author of the so-called "first complete survey" (Bosello et al. 2006), which projects Tol's earlier results forward to 2050, adding the assumption that there are no heat-related deaths from respiratory disease, as well as cardiovascular disease, in rural areas. Neither study provides any support or documentation for the assumed absence of heat-related rural deaths.

The result of these assumptions is that countries with large rural populations, above all China and India, are projected to have huge reductions in mortality due to warming. Specifically, Bosello et al. project that by 2050 a temperature increase of 1°C will reduce annual mortality by 850,000 worldwide; of that projected reduction, 810,000 occurs in China and India alone. A truly complete global survey might have investigated whether a country like India, where heat waves often reach 49°C (120°F), is really immune to heat-related rural deaths (De et al. 2005).

## 3 Costs, benefits, and consensus

A mantra repeated throughout *Cool It* is the belief that other problems are more urgent than climate change, and more cost effective to address. Cost–benefit analyses of a range of competing priorities, written for Lomborg's earlier "Copenhagen Consensus," form the basis for this belief. That consensus was reached among eight like-minded economists, sitting in judgment on cost–benefit analyses performed by a few dozen other economists. As Lomborg modestly describes it,

> A panel of top level economists, including four Nobel laureates, then made the first explicit global priority list ever (43).

There are three separate problems with the notion that cost–benefit analysis has shown other issues to be higher priorities than climate change: there are no meaningful monetary valuations for many of the benefits of climate mitigation; the range of policy options considered by the "consensus" was arbitrarily truncated; and the calculations in the "consensus" cost–benefit analyses rely heavily on wishful thinking.

Cost–benefit analysis compares the costs and benefits of a policy proposal or other initiative. It makes the seemingly innocuous assumption that policies should only be adopted if the benefits exceed the costs. This comparison, however, is only appropriate if both costs and benefits can be fully quantified and meaningfully expressed in monetary terms – and that is rarely the case in health and environmental policy. Typically, the costs of environmental protection are largely or entirely monetary, while the benefits include such priceless values as protection of life, health, endangered species and unique ecosystems, and the rights and needs of future generations. Economists who are committed to cost–benefit analysis have invented surrogate prices for many priceless health and environmental values, but both the methodology and the results of this process are problematical (Ackerman and Heinzerling 2004).

In the case of climate change, it is possible, at least in principle, to calculate the cost of emission reductions. On the other side of the balance, the benefits of reducing carbon emissions include decreases in all manner of harms to people and nature, and a lowered probability of truly catastrophic, irreversible changes. What is the dollar value of a human

life saved, of a coral reef or a polar bear surviving undisturbed in its natural habitat, or of the lowered chance of catastrophe due to a slowdown in the rate of melting of the Greenland ice sheet? Does the dollar value of a human life depend on the income of the person whose life is saved? Simply asking these questions reveals why there are no meaningful answers. But without those answers, cost–benefit analysis is unable to incorporate and measure the most important benefits of climate change mitigation.

The second problem is the arbitrarily limited range of policies considered in the Copenhagen Consensus, and discussed in *Cool It*. Climate change was weighed against policies to address disease, malnutrition, and scattered other problems; reducing barriers to free trade somehow made it onto the list. The option of reducing US military spending, on the other hand, was overlooked by the assembled economists, although they did evaluate efforts to limit civil wars in Africa.

But what public policy choice does their deliberation correspond to? There is no fixed sum of money which is available for combating climate change, disease, malnutrition, barriers to free trade, civil wars in Africa and the other Copenhagen Consensus options. The policies they considered are not the only things that governments spend money on, nor are they the only ways in which rich countries affect poor people in developing nations. "Which do you prefer, climate change mitigation or AIDS prevention?" is a trick question, to which the answer should be that you don't have to choose. In the USA, imagine how much progress on all the "consensus" issues could be made with the hundreds of billions of dollars spent each year by the Pentagon. Or one could equally well favor reducing farm subsidies or tax breaks for energy companies; or rolling back some of the recent, generous tax cuts for the rich; or raising foreign aid and social and environmental spending closer to the levels seen in other industrial countries. The larger point is that the funding available for climate initiatives depends on the politics of the USA and other rich countries, not on the technicalities of cost–benefit analysis or the merits of assorted other policy options.

A third problem is that the details of the Copenhagen Consensus cost–benefit analyses do not withstand scrutiny (Ackerman 2005). A different economist analyzed each policy; methods varied widely from one case to the next. Popular policies often received fantastically exaggerated benefit estimates, with little or no empirical support. A global program of AIDS prevention measures was said to have benefits worth 50 times its costs, based on optimistic extrapolation from experience with a pilot program; in contrast, malaria prevention had benefits worth "only" 19 times its costs, based on experience with implementing large-scale programs. On the basis of these numbers, the Copenhagen Consensus judged AIDS prevention to be a higher priority than malaria prevention. Removal of trade barriers was assumed to produce a huge boost in developing country growth rates – and that gain was assumed (without evidence) to continue undiminished for 45 years after trade liberalization. The epitome of this numerical puffery occurred when one nutrition program was estimated to produce total global benefits worth 200 times its costs. None of the local case studies supporting that summary figure had benefit–cost ratios greater than 84, and some were as low as 6.

In the Copenhagen Consensus paper on climate change, William Cline attempted a more sober and rigorous cost–benefit analysis, resisting the temptation to award fantastic numbers to his favorite policies. Using a modified version of William Nordhaus' DICE model, Cline showed that active climate mitigation scenarios had benefit–cost ratios of 2–4. The other Copenhagen Consensus economists were dismissive of Cline's results, rejecting his choice of a discount rate – and pointing out that his benefit–cost ratios were far below those claimed for the rival policy options. In *Cool It*, Lomborg cites one of the other "consensus" economists' critique of Cline, but not Cline's analysis itself.

## 4 Three hundred years of Kyoto

Climate science has been debated for years and is becoming well-known; climate economics may be less familiar terrain. Here Lomborg attempts to define the boundary of acceptable opinion, offering summary judgments about what "all" analysts believe:

> All major peer-reviewed economic models agree that little emissions reduction is justified. A central conclusion from a meeting of all economic modelers was: "Current assessments determine that the 'optimal' policy calls for a relatively modest level of control of $CO_2$" (37).

The meeting in question was a workshop of 19 people, not all of them economic modelers, held in 1996.

The attempted demarcation of the boundaries of "all" economic thought merges with Lomborg's reverent attitude toward Richard Tol, the most frequently cited author in the bibliography. Tol is described as having written "the biggest review article of all the literature's" estimates of the social cost of carbon, i.e. the monetary value of the damages done by emitting one more ton of $CO_2$ (30). But Tol's contribution is not confined to writing the biggest article, as Lomborg explains:

> When I specifically asked him [Tol] for his best guess, he wasn't too enthusiastic about shedding his cautiousness – true researchers invariably are this way – but gave a best estimate of two dollars per ton. This means that the damage we will cause by putting out one more ton of $CO_2$ is likely two dollars... If we tax it at $85, as proposed in one radical report, while the real damage is two dollars, we lose up to $83 of social benefits (31).

From this passage in the text, the reader has to consult both the notes and the bibliography in the back to find that the "radical report" in question is the Stern Review, published in Britain by that notorious radical organization, Her Majesty's Treasury. The thoughtful, extensively researched Stern Review comes in for extended criticism from Lomborg, while Tol's previously unpublished – and astonishingly low – personal guess at the social cost of carbon is simply pronounced correct: "We should tax $CO_2$ at the economically correct level of about two dollars per ton..." (152).

In Lomborg's view, it is not only Tol who speaks for the economics profession as a whole. Several statements about what "the models" as a whole show about climate economics (34–36) are documented only with citations to a single model developed by Lomborg's other favorite economist, William Nordhaus. Likewise, Nordhaus is the only economist cited in support of a discussion of the vast cost of the Kyoto Protocol over the next century (33–34). The long time span may surprise those who recall that the Kyoto Protocol extends only to 2012. Nordhaus, however, has invented what he describes as the "Kyoto forever" scenario, in which the provisions of the Kyoto Protocol are extended indefinitely – allowing the attribution of many years' worth of costs to this short-term proposal (Nordhaus and Boyer 1999).

A widely quoted Nordhaus estimate is that the Kyoto Protocol would impose global costs of $716 billion; the original study shows that this is the present value of 300 years of "Kyoto forever," assuming that carbon emissions trading occurs only among Annex I countries (Nordhaus and Boyer 1999, Table 6B).[2] This seemingly large total is less than

[2] Based on the 1998 draft of the manuscript; the 1999 Energy Journal special issue is not widely available.

$2.5 billion per year over the 300 year span, not even 40¢ per person per year at the world's current population. The same study, moreover, shows that if global emissions trading is allowed, the 300 year total cost drops to a present value of only $59 billion, equivalent to $0.2 billion per year, or less than 3¢ per person per year. Thus if the world were to do something as utterly bizarre and inconceivable as extending the Kyoto Protocol unchanged for 300 years, and if Nordhaus was correct about the resulting costs, almost all of the costs could be avoided by introducing global emissions trading.

Lomborg feels sure that this sort of nonsense is what "all" economics looks like. But Nordhaus, Tol, and their admirers are not the whole of the economics profession. The Stern Review, and the work of the economists in the right-hand column of Table 1, above, provide important examples of alternatives – and there are many others as well. There are numerous published estimates of the costs of the Kyoto Protocol, most of them by economists who somehow missed the 1996 workshop of "all" modelers – and failed, as well, to be mentioned in *Cool It*. Lomborg's suggestion that all economic models produce more or less the same results is dead wrong; in fact, estimates of Kyoto costs have differed so widely that there have been three recent meta-analyses seeking to explain the sources of disagreement (Lasky 2003; Barker and Ekins 2004; Fischer and Morgenstern 2005). Factors such as the extent of emissions trading, the uses of government carbon tax or permit auction revenues, the treatment of co-benefits of carbon reduction, and several technical assumptions about economic modeling turn out to have major impacts on the estimated costs. One of the meta-analyses concluded that if policies implementing the Kyoto Protocol were "expected, gradual, and well designed," the net costs of mitigation for the U.S. would have been insignificant (Barker and Ekins 2004).

## 5 Conclusion: Economics that takes climate seriously

Finally, suppose that we look beyond the mistakes and biases of *Cool It*. What would be needed to create an economic analysis that takes the climate crisis seriously? There are three essential elements of a new climate economics: discount rates that reflect our responsibility to the future; a central focus on the role of uncertainty; and a reinterpretation of the costs of climate policy.

### 5.1 Discounting the future

The costs and benefits of climate change, and of climate policies, are spread out across decades and centuries. Thus total costs and benefits are inevitably present values, based on the choice of a discount rate. Any comparison of the total costs and benefits of climate scenarios is a statement about present values, and is valid only for one discount rate; a different discount rate would yield different totals.

Much has been written about the economic and philosophical issues involved in choosing discount rates, but there is nothing approaching a resolution to the debate. It is indeed a choice; the appropriate discount rate for public policy decisions spanning many generations cannot be deduced from private market decisions today, or from economic theory. A lower discount rate places a greater importance on future lives and conditions of life. To many, it seems ethically necessary to have a discount rate at or close to zero, in order to respect our descendants and create a sustainable future.

In practice, the discount rate is decisive for economic evaluation. In a model such as DICE, switching from a high to a low discount rate can change the social cost of carbon

from a very low to a very high value, thereby supporting much more extensive mitigation policy. Among many other sources, see the thorough discussion of discounting in the Stern Review; Cline's paper for the Copenhagen Consensus; and my own sensitivity analyses with the DICE model (Cline 2004; Ackerman and Finlayson 2006; Stern 2006).

### 5.2 Understanding uncertainty

Climate outcomes are uncertain in several respects, ranging from short-term variations in weather to the long-term sensitivity of the climate to greenhouse gas concentrations, to the probability of irreversible catastrophes. Lomborg's embrace of the A1B scenario as "the standard" suggests an all too common strategy for economic analysis: adopt a best guess or expected value as the point estimate, and ignore the question of uncertainty.[3] The Stern Review, in contrast, highlights the role of uncertainty, applying a Monte Carlo analysis in which dozens of parameters are allowed to vary around the current best estimates. This expanded treatment of uncertainty is a principal reason why Stern's estimates of the social cost of carbon are higher than those of many other economists. Since people are risk-averse, including both better-than-average and worse-than-average possibilities in the analysis makes climate change look more threatening: the better possibilities have limited effect, while the worse ones loom large.

In an important recent contribution to the economic theory of climate change, Martin Weitzman argues that the problem of uncertainty is even deeper than this (Weitzman 2007). Calculations of expected values, even when done with Monte Carlo analyses, assume a known probability distribution for each uncertain outcome or parameter – often a distribution such as the normal, with thin tails. But Weitzman points out that we are inevitably inferring the probability distribution from a limited amount of empirical information, resulting in an estimated distribution which itself is uncertain, and thus has fat tails. Such a distribution defeats the calculation of expected values; in the tail of the distribution, climate damages can grow faster than the probability of those damages declines. If a crucial parameter such as climate sensitivity is in effect being estimated from N observations, we know very little about the tails of the distribution describing events that occur with probability 1/N or less. Yet with no firm upper bound on the damages that could result, it is these low-probability, high-cost outcomes that people inevitably worry most about (a survey of expert opinion about the expected severity of climate damages, carried out and relied on by Nordhaus, itself turns out to have a fat-tailed distribution, with a noticeable minority of truly ominous estimates; see Roughgarden and Schneider 1999). Weitzman's densely mathematical argument is new and not yet well-known, but it provides rigorous support for a strongly precautionary approach to climate policy, consistent with scientific warnings that emphasize worst-case risks.

### 5.3 Interpreting the costs of climate policy

The implicit assumption of cost–benefit analysis is that the costs of new initiatives are bad, and must be outweighed by the benefits in order to justify changes in the status quo. Since

[3] Nordhaus goes one step beyond that, including the costs of a moderately large, low-probability catastrophic event that becomes more probable as temperatures rise; in other respects, his model remains based on estimates which are treated as certain.

consumers are assumed to have chosen whatever purchases bring them the greatest welfare, market outcomes are thought to be optimal; any new costs can be interpreted as decreasing welfare. This presumes that consumers are well informed about the implications of their choices, which may be quite inaccurate in the case of carbon emissions and climate change. And in terms of equity, the market makes decisions on the basis of "one dollar, one vote." Therefore, unconstrained market outcomes are only optimal if one accepts the existing distribution of resources; a redistributive policy that imposes costs on the wealthy could increase welfare for the majority. Since the poorest parts of the world will generally suffer more, and sooner, than the rest of us from climate change, the question of equity should be central to climate policy.

Another implicit assumption is that the costs under consideration are painfully large, perhaps prohibitive, making it of utmost importance to guard against expensive new undertakings. But in climate models estimating impacts over a century or more, the costs must be interpreted in the context of expected economic growth. Costs as great as 5–6% of GDP by 2100 – much higher than the Nordhaus estimates for Kyoto, or even the Stern Review estimates for global mitigation costs – would amount to only a trivial delay in the ongoing growth of income assumed by most models. In an economy where per capita incomes were growing at 2% per year, people would on average be 6.3 times as rich in 2100 as they are today (in 2007). If climate mitigation costs amount to 6% of output, the result would be a 3 year delay in the century of growth: income net of climate costs would not reach 6.3 times today's level until 2103 (Azar and Schneider 2002).

There is yet another sense in which the costs of climate policy need to be reinterpreted. An effective climate policy is not a simple subtraction of resources from the existing market economy; rather, it involves choosing a different path for future economic and technological development. The costs of such a policy do not disappear; they get spent on creating a new set of industries. Technological change is imperfectly understood in economics, but it is a path-dependent process characterized by economies of scale in the emerging industries. Public initiatives can lead to the creation of successful new development paths: the "costs" of decades of government, particularly military, investment in microelectronics after World War II led to the more recent successes of private enterprise in extending those technologies and applying them in computers, cell phones, and countless other products. In hindsight, it would seem odd to describe the early public expenditures on miniaturizing electronics as costs that reduced welfare; rather, they shaped the development path of late twentieth and early twenty-first century technologies and industries. As that process advanced, new jobs, incomes, profits, and products were created, and our way of life was transformed.

The massive effort that is needed to address the climate crisis today could do the same for the decades to come. Suppose that we spend money today to launch a new set of technologies and industries based on maximizing energy efficiency, renewable energy production, and sequestration, thereby creating the jobs, incomes, and products that shape the life of the next generation. Our descendants will not blame us for having reduced the level of short-term shopping opportunities at the mall. They will be especially happy to get a more tolerable climate as part of the package. And that – unlike Lomborg's fantasies – would really be cool.

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