The Big One:
A Review of Richard Posner's *Catastrophe: Risk and Response*

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ABSTRACT: Richard Posner's *Catastrophe: Risk and Response* (Oxford, 2004) examines four risks whose worst cases could end advanced human civilization or worse: asteroid impacts, a catastrophic chain reaction initiated in high-energy particle accelerators, global climate change, and bio-terrorism. He argues that these all warrant more thought and response than they are receiving, and that they can usefully be assessed using a simple analytic framework based on cost-benefit analysis. This essay reviews knowledge of these risks and critically examines Posner's claims for a consistent analytic approach. While the conclusions that each risk merits more thought and effort appear persuasive, these rely on *ad hoc* arguments specific to each risk. The general analytic claims do not hold up well, as Posner develops his proposed framework thinly and applies it unevenly. Applying such a framework consistently to catastrophic risks would require engaging some fundamental problems that Posner does not address. The book's major contributions are to identify and describe these risks, highlight the inadequate attention they are receiving, and advance a persuasive argument for their more serious examination.

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Despite the epidemic of anxiety that afflicts modern life, few people appear to spare any attention to worry about the biggest things. How might the world end? Those interested in this question are most likely to frame it in religious terms – but what about secular apocalypse? Are there known physical or biological mechanisms that could end life as we know it? And if so, what are they and what, if anything, can we do about them?

If you don't have enough to worry about, or if you want to worry on a larger scale, this book – by the astonishingly prolific appeals judge, law professor, and amateur economist Richard Posner – is for you. Posner thinks big. He is concerned with catastrophic risks, those that in their worst case could end advanced civilization, all of humanity, or life on earth. He asks what we know about potentially catastrophic risks, how we should think about them, and what we should do about them.

What are these risks? Posner identifies four categories – natural catastrophes, scientific accidents, unintended consequences of productive human activity, and intentional catastrophes, created by malevolent human agency – and outlines, to varying degrees of detail, several risks that fall into each category. Most of these he quickly dismisses, either because they are not big enough to count as true catastrophes (e.g., earthquakes, volcanoes, natural pandemics, and biodiversity loss), or because decades of scientific advance would be needed to turn them into real threats (e.g., omnivorous self-replicating nano-machines, or super-intelligent machines attacking or enslaving humans), although he keeps these around long enough to reveal a fondness for post-apocalyptic fiction. Early chapters include detailed and affectionate accounts of two futuristic nightmares, the human-enslaving machines in the film "the Matrix," and the post-climate-catastrophe society in Margaret Atwood's novel "Oryx and Crake."

Four catastrophic risks remain, one in each category: asteroid impacts, a hypothetical particle-accelerator accident called the "strangelet scenario," global climate change, and bioterrorism. Posner provides fairly detailed summaries of present knowledge of each, and proposes counter-measures. His broadest aim is to corral these risks into some common mode of reasoning, to pursue general insights and a rational approach to management. At this high level of generality, he makes four claims.

1. All these risks are likely enough to warrant serious examination, and some are growing more likely.
2. They are not getting attention commensurate with their severity, partly due to known psychological, cultural, and social factors that make it hard to think clearly about them.
3. Despite their extreme and unprecedented character, these risks can usefully be examined with a simple analytic framework based on cost-benefit analysis, even if estimates of probabilities and consequences are only wide bounds or slightly informed speculation.
4. Applying these analytic tools suggests that we should be doing substantially more to avert these risks than we are.

Be forewarned. The book is full of irritations, eccentricities, and vanities, with signs of extreme haste everywhere. It is a mess of facts and ideas – good and bad, relevant and irrelevant, supported and unsupported, and nearly all half-baked at best. The organization is terrible, filled with multiple repetitions, odd topic jumps, and apparently random digressions. Seemingly arbitrary and unsupported opinions appear frequently, such as a strange rant on how creators of computer viruses should serve at least five years prison time. So also do irritating didactic tutorials on elementary analytic points: here are a few paragraphs on discounting, here are a few on how to generate chaotic behavior from a simple quadratic difference equation. The assembly of material from other sources, particularly the summaries of scientific knowledge of his four risks, is so undigested that extended passages read like an unprocessed summary of sources prepared by a team of research assistants.

And yet. Every ten pages or so, there are a few paragraphs where Posner seems to start paying attention, and you see the application of a sharp, restless intelligence – still thinking on the fly, but now making coherent and provocative arguments. The large-scale arguments and proposals for action, while roughly drawn, are in some instances persuasive – and refreshingly challenging, not least in the glee with which they cut across ideological lines. There is plenty of food for thought here.

Such haste, breadth, and fondness for provocation are all part of Posner's *modus operandi*, but it is neither interesting nor useful to catalog all the resultant small-scale faults. Rather, one must step back to view the large-scale argument and recommendations, and ask how well these survive the thousand underlying defects. Unsurprisingly, the verdict is mixed. To engage these arguments, however, it is necessary to know something about the risks. Information about these is spread through much of the book, which is a shame since these are in many ways the most interesting parts. Here follows a condensed and organized summary.

Four Catastrophic Risks

Of the four risks, Asteroid impacts are the only one whose probability distribution of harms can be objectively estimated, by tracking the space objects that are big and close enough to threaten the Earth and by observing the results of past impacts on the Earth and Moon. The inventory of potentially hazardous asteroids (PHAs) – defined as those with diameter 1 kilometer or larger, and whose orbits can bring them within 7.5 million kilometers of the Earth (about 5 percent of the Earth-Sun distance or twenty times the Earth-Moon distance) – is actively growing, and so already substantially larger than when Posner wrote in early 2004. There are estimated to be perhaps 200-250 PHAs, of which 159 have been catalogued. If you expand the count to include objects that are either smaller or more distant, the numbers grow sharply: there are 773 catalogued objects this close if you count all that are bigger than 100 meters, while there are 836 this big (1-kilometer-plus) if you count all those that pass within a larger band around the Earth's orbit (within 30 percent of the Earth-Sun distance). The PHAs – those that are both big and close – are the most important. The 159 of these that have been found include nine that might be 5 kilometers or larger, of which the largest might be roughly 8 kilometers[1] -- close, given the uncertainty involved, to the 10-kilometer size believed to have caused the great extinctions of 65 and 250 million years ago. A 10-kilometer impact, estimated to occur every 50 to 100 million years, would kill most or all people on Earth through the combined effects of fire, shockwave, tsunamis, and several years' obstruction of sunlight. Smaller asteroids strike more often and cause less destruction: how much less depends both on their size and composition, and on where they strike. Proceeding from largest to smallest, one to two-kilometer strikes occur once every 100,000 to one million years, and might destroy an area of half a million square kilometers (e.g., California or France) if they hit land. An ocean strike would cause hemispheric or global tsunamis, making the destruction greater and more widespread. Objects of ~100 meters strike every few thousand years, destroying the area of a large city. The most recent significant impact occurred in Siberia in 1908, a ~50-meter asteroid that exploded in the air and released about the energy of a small hydrogen bomb (~ 1 – 2 megatons), destroying a 50-kilometer circle of forest. Impacts of this size occur once every few centuries. Finally, 10-meter asteroids strike the Earth more than once a year, making upper-atmosphere explosions the size of early atomic bombs, roughly 20 kilotons. Summing the estimated risks from all asteroid impacts gives an expected 1,000 to 10,000 deaths per year, almost all of them from the largest and rarest events.

The one risk that could destroy the Earth even more thoroughly than a large asteroid arises from a series of events, called the "strangelet scenario," that could be triggered by heavy nuclei colliding in high-power particle accelerators. The products of such collisions can include subatomic particles called strange quarks. If particles containing strange quarks (called "strangelets") are stable and negatively charged (both believed highly unlikely), they will approach and fuse with nearby nuclei, converting some of their matter to strange quarks and yielding a larger strangelet. If the strangelet remains stable and negatively charged as it grows (also believed highly unlikely), the process will continue until it runs out of nearby matter – reducing the Earth and everything on it to a hyper-dense sphere of strange matter roughly 100 meters across. The sphere would immediately explode like a stellar supernova, not that we would care at that point. The essence of this risk is that it is a chain reaction, by which some foreign form of matter assimilates and transforms the normal form. Such chain reactions are known in protein folding (including the development of prion diseases such as mad cow disease) and in crystal formation: Posner draws the analogy to a 1998 event when stocks of the AIDS drug Ritonavir began spontaneously converting to an alternate, clinically ineffective crystal form. But a far more apt analogy – and a catastrophic one, albeit fictional – is to "Ice-9,"the alternative crystal form of water with a melting point of 114° F that figures centrally in Kurt Vonnegut's novel "Cat's Cradle."

Although no stable strange matter has ever been observed, this scenario generated enough controversy around the startup of a new collider at Brookhaven National Laboratory in

[1] The size of these objects is inferred from their brightness, and has substantial uncertainty. The nine are those with absolute magnitude (H) < 15.0, of which the brightest has H = 14.1. H = 15.0 corresponds to diameter 3 – 6 km, 14.0 to 4 – 9 km. (Data from NASA's Near Earth Object Program, at neo.jpl.nasa.gov, accessed May 22, 2006).

2000 that groups at Brookhaven and the European laboratory CERN conducted risk assessments. Most experts regard a strangelet catastrophe as vanishingly unlikely on theoretical grounds, but the risk is extremely hard to characterize. In addition to theoretical arguments, both assessment teams also tried to estimate upper bounds for the probability empirically, based on the event's not having occurred in the lifetime of the Moon and other bodies unshielded from cosmic radiation. The CERN team put the upper bound at 1 in 500 million per year, the Brookhaven team at 1 in 500,000 per year with two alternative cases of 1 in 50,000 and 1 in 500 billion under different assumptions (Glashow and Wilson 1999, Kent 2004). Since the Brookhaven collider began operation in 2000, no strangelet has been observed, and subsequent work has strengthened the theoretical case that the catastrophic scenario is impossible (Madsen 2000). Still, even proponents of large colliders acknowledge that doomsday scenarios cannot be definitively excluded, and still more powerful colliders continue to be developed.

The remaining two catastrophic risks, global warming and bioterrorism, are more widely known to most educated citizens, although not necessarily easier to characterize. Global warming is caused by emissions of infrared-absorbing gases from human activities, principally burning fossil fuels, which have raised the atmospheric concentration of CO_2 from 280 parts per million (ppm) before the industrial revolution to 380 ppm today and are likely to increase it to 500 to 1000 ppm by year 2100. Since higher concentration of CO_2 and other greenhouse gases warms the surface – an effect already evident in rapid warming since 1970 – these increases are projected to bring further global-average warming of 1.4 to 5.8° C by 2100. This is projected to bring many serious hydrological, ecological, and socio-economic impacts, although the details of these are not well characterized and not all potentially serious mechanisms of impact are even identified.

Even if global warming happens smoothly and incrementally, this range of projected change would appear to warrant concern. After all, even the bottom of the range is double the warming of the 20th century. The top of the range, about ten times the 20th-century warming, would represent a change about as big (although in the opposite direction) as the difference between an ice age and today's climate. This range of changes does not worry Posner, however, who judges them too small to justify the cost of stopping them. Rather, he worries about several potential mechanisms of abrupt, extreme climate change or catastrophic impacts: large sea-level rise (5 to 6 meters or more) from loss of major continental ice sheets in Antarctica or Greenland; sharp reduction or shutdown of the Atlantic Ocean circulation that brings warm water to high latitudes and mild climates to western Europe; various positive feedbacks through which global warming could trigger massive release of naturally stored greenhouse gases, generating a runaway heating; or, in the opposite direction, various ways that global warming could so change the radiative properties of the atmosphere as to trigger rapid global cooling – bringing a new ice age or worse, a "Snowball Earth" in which ocean surfaces freeze from the poles to the tropics. Although prominent scientists have argued for the importance of considering such extreme and believed unlikely events (Broecker 1987, Oppenheimer and Alley 2005, Schneider et al 1998, Hoffman et al 1998), they are barely mentioned in official assessments (IPCC 2001a). No attempt has been made to characterize their probability in a risk assessment,[2] and nor does Posner attempt to do so.

Of the four risks considered, climate change has the most prominent policy debate and most acute public disagreement over its nature and severity. It consequently most strongly requires Posner to engage the politics and sociology of scientific knowledge, which he does offhandedly but mostly with good sense. He is appropriately scathing about the few climate contrarians for their sloppy argument, polemical tone, and preference for forums where they do not face scientifically informed criticism. He notes correctly that the seeming uncertainty and dissent in popular and policy outlets is belied by a strong consensus among scientists that global climate change is real, human-caused, and serious – and even reports his own informal survey of the scientific literature, in which the consensus view outweighed even mild skepticism by 53 to 2.[3] And he correctly notes that scientific uncertainties broaden the distribution of potential climate futures in the direction of both higher and lower risks, and so (assuming risk aversion) typically support stronger action than best-guess point estimates.

And yet in a few instances, Posner uncritically accepts contrarians' claims that even a little investigation or reflection would show to be preposterous, most strikingly the claim that scientists exaggerate the risks of climate change as a ploy to increase their research funding.[4] This is nonsense. Climate-change activists advocate efforts to reduce emissions and adapt to the climate change we cannot avoid. Such efforts would require increased research funding for energy efficiency, non-fossil energy sources, and carbon sequestration, but not for climate science. In a budget-constrained world, such a program would probably reduce, not increase climate-science research. Consequently, when climate scientists join these calls for action to limit climate change, they act against their own professional interests. To most effectively increase funding for climate research, an opportunistic researcher should argue that the risks are not well enough established to warrant action, so we need more climate research to decide whether and how to act. But this is precisely the argument being advanced by the contrarians, not the mainstream climate scientists and activists whom they denounce.

For his fourth risk, in case you are not scared enough, Posner turns to bioterrorism. Biological weapons produced for terrorist purposes could be far more devastating than either chemical or nuclear weapons, or natural pathogens. A bacterium or virus with ideal killing properties – a high mortality rate, a long infectious incubation period, and efficient airborne transmission – and for which there was no effective vaccine or treatment, could potentially kill most or all people on Earth. While naturally occurring organisms are unlikely to grow this lethal – if you are a bacterium, it is not advantageous to kill your entire host population – genetic manipulation of existing disease organisms

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2 Although for a highly instructive experiment in which a dozen eminent climate scientists were asked to do so anonymously, see Morgan and Keith (1995).

3 This exercise essentially repeats the larger exercise of Oreskes (2004).

4 This charge has been widely made, most famously in Michael Crichton's polemical novel "State of Fear" (2005). It was most recently advanced in a Wall Street Journal op-ed on April 12, 2006 (Lindzen 2006).

(e.g., smallpox or other pox viruses, or the hemorrhagic viruses Marburg and Ebola) could in principle produce new bugs this bad. While the specific difficulties of creating an effective bioterrorist agent are not well known (at least publicly) and may be severe, general capabilities for the required types of genetic manipulation are widely dispersed. About ten countries are known or suspected to have bioweapons programs, and terrorist organizations have tried to develop them. Suitable lab facilities exist in dozens of countries.

How to Think About These Risks: a Proposed Analytic Framework

After characterizing these risks, Posner sets out his proposed analytic framework, which is basically cost-benefit analysis with a few heuristic extensions and approximations to handle the extreme and novel features of these risks. He is impressively bold and sometimes wildly arbitrary in estimating probabilities and consequences for purposes of argument – adopting or rejecting estimates from prior sources as he pleases, or making numbers up when none is available. The benefits of operating the contested collider at Brookhaven Lab are $250 million per year, or alternatively zero; catastrophic global warming brings a permanent 20% loss in Gross World Product; and so on.

He then proposes four heuristic extensions to a basic cost-benefit analysis framework, although these differ greatly in how carefully he develops them and how much he uses them. The first, a sketch of a few alternatives to conventional discounting in trading off present and future consequences, is thinly developed and not subsequently used. The second, which Posner calls a "modest version of the precautionary principle," is less a method in his analytic framework than a suggested bias in estimating costs and benefits. Based on several bodies of evidence – e.g., the weak observed association of individual happiness with wealth, the increasing deflection of consumption into positional goods at high income levels, and risk aversion over healthy lifespan – he argues that the prospects for advancing human welfare by increasing consumption beyond present rich-world levels are slim. Consequently, increases in material wealth beyond this level are unlikely to outweigh any accompanying increase in catastrophic risks. This may well be correct, but Posner makes no attempt to sharpen the approach or even state clearly when he is using it. Perhaps it is embedded in the estimates of costs and benefits he uses throughout the book. He correctly criticizes the original Precautionary Principle as "too squishy," but this alternative is barely less so.

The other two methods are developed more extensively and used at least to some degree in his subsequent analysis of the four risks. The third, which he calls "inverse cost-benefit analysis," involves rearranging the terms of a conventional risk analysis to put a bound on an unknown probability of a catastrophic risk. He compares actual annual spending to avoid a risk with the loss that would be incurred if it happened, and treats the ratio of these as an estimate of the annual probability of occurrence that is implied by this spending level. If the probability so calculated is much smaller than the best estimate of the true probability, he concludes that avoidance expenditures should be increased.

This simple calculation is a variant of the "Hand rule," an early landmark of law-and-economic reasoning from tort law (Hand 1947). In the case *U.S. v. Carroll Towing*, Judge Learned Hand proposed that under a negligence standard, an injurer should be liable for failing to take a precaution against a risk when the cost of the precaution is less than the expected value of the risk. Posner himself (1972) noted that when the Hand rule is interpreted as a relationship among *marginal* avoidance costs and damages, it motivates optimizing agents to make the socially optimal level of avoidance effort. But Hand's decision was famously ambiguous on whether he intended the rule to apply to marginal or total effects. If to total effects, the rule gives optimality only under risk neutrality plus highly restrictive assumptions about the effect of avoidance efforts. If expenditure on avoidance E is assumed to reduce the probability P of a fixed loss L, then the Hand rule in total effects (i.e., requiring $E = P*L$) produces optimality only if $P(E)$ is of unit elasticity everywhere, i.e., $P(E) = k * E^{-1}$. Even assuming a constant-elasticity (but not unitary) relationship $P(E) = k*E^{-\alpha}$, the ratio E/L at the optimum is not P but $\alpha * P$. This makes sense: if the effect of spending to reduce P is small, we will want to spend less, for a given L.

In this book, Posner's inverse cost-benefit criterion clearly compares total, not marginal effects. Consequently, if taken as a precise decision criterion, it gives socially optimal outcomes only under the highly restrictive assumption of unit elasticity in risk reduction. On the other hand, Posner states the condition very loosely: he proposes it only for order-or-magnitude comparisons between E/L and P to give guidance on the direction E should be changed. Moreover, he makes no reference to the dependence of P on E, stating single order-or-magnitude estimates for the probabilities of his four risks with no mention of how these might be being reduced by the avoidance efforts already being made, or be further reduced by additional efforts. The optimal expenditure on reducing these risks might in extreme cases be far from that implied by Posner's inverse cost-benefit condition. For example, a risk might be catastrophic, but if no available measure can reduce its probability then the optimal level of avoidance expenditure is zero. Alternatively, avoiding some risk might be so easy that it can be reduced to zero by expenditures much less than its initial expected value. Despite this sloppiness, we might be tolerant in assessing this rule of thumb, since Posner acknowledges he does not address the cost or effectiveness of specific responses to his four risks, and only uses this inverse benefit-cost criterion for order-of-magnitude comparisons between numbers that are far apart.

It is in valuing lives that Posner makes his strangest proposal. He endorses the standard literature – which values a rich-world statistical life at a few million dollars, based on people's observed willingness to buy and sell small risks – but proposes a hundred-fold reduction in this value when dealing with probabilities of death smaller than 10^{-6}. Note that the proposal is not for a reduction in willingness to pay to avoid risk, which decreases in proportion to the risk given a constant value of life, but for a reduction in the value of life – i.e., the willingness to pay per unit risk reduction. Three points are advanced to support this adjustment, but none of them is remotely persuasive. First, he argues that the literature on observed risky choices does not include such small risks – but it's hard to imagine how it could, since even with constant $5 million value-of-life the sums involved would be a few dollars or less, and this provides no affirmative evidence for the proposed reduction in value of life. Second, he argues that studies of risk perception show people tend to ignore small risks – but in fact, as he acknowledges a few paragraphs later, the result is more ambiguous. People tend to ignore sub-threshold probabilities unless the risks in question have some other attributes that draw attention to them – e.g., they are unknown, uncontrollable, or dreaded – in which case they tend to be over-estimated. Finally, he argues that willingness to accept risks and to pay to avoid them vary non-linearly as risks grow large, and so by analogy might also vary non-linearly at small risks. But the nonlinearity at high risks emerges from consistent utility formulations that converge to a constant value of life for all risks below some probability bound, typically of order 10^{-3} (Howard 1980). Thinking coherently about how to respond to extremely low-probability, high-consequence events may pose many difficulties, but this quick-fix does not help. Fortunately, Posner only uses this strange reduction in value of life to provide lower-bound values for the two most unlikely risks he considers, a 10-kilometer asteroid strike and the strangelet scenario. Since he concludes in each case that increased protection efforts are warranted, replacing his arbitrarily reduced value of life with a more conventional value would only strengthen the conclusion.

Back to the Four Risks: How does the Framework Help?

Whatever consistency of analytic approach Posner has achieved, it quickly breaks down when he begins applying it to his four risks. The analysis of asteroid impacts is the most straightforward, and except for a couple of minor points, the most persuasive. He states that about $4 million is presently spent annually to assess and avoid the risk. Using his reduced value of life, he estimates the cost of a 10-km asteroid extinction event as $600 Trillion: 6 billion deaths, doubled to account for future lives not lived, at $50,000 per life. The inverse cost-benefit heuristic then implies an annual probability of about 1 in 100 million – similar to actual estimates of the probability of such a strike, so this level of expenditure may be about right. But the answer changes when a less catastrophic but more likely event is considered, a 2-kilometer strike that kills 1.5 billion people, with an annual probability of about 1 in 250,000. Because the probability of this catastrophe is greater than 10^{-6}, Posner now uses the more conventional $2 million per life, giving a total cost of $3 quadrillion.[5] The inverse cost-benefit heuristic now implies an annual probability of about 1 in 800 million – three orders of magnitude smaller than the estimated probability of such a strike. He concludes that we should be spending more to assess and respond to this risk.

This conclusion appears persuasive, and becomes even more so if we reject Posner's reduced value of life for the larger and rarer event and so increase its cost a hundred-fold. The distribution of risks is sufficiently well characterized that the only difficulty in assessing them is deciding how to value low-probability, catastrophic outcomes at the tail of the distribution. Whether these are evaluated by their expected value or with risk aversion, the assessment leads to an easy decision to do more. This argument does not, of

[5] In this calculation, deaths are not doubled to account for future lives not lived, because this event does not end humanity

course, say what more should be done, or how much of it, which would require detailed assessment of the cost and effectiveness of specific risk-reduction measures. Posner supports two existing proposals to deploy new telescopes dedicated to finding and tracking all potentially threatening objects. An effective response to manage this risk would also of course require developing the capability to deflect objects that appear to pose high risks, on which nothing is being done at present. But abstracting from these important practical matters, the conclusion that more should be done appears clear.

His analysis of the strangelet scenario is more problematic. Disregarding "moderate" catastrophes to focus exclusively on total annihilation of the Earth, Posner once again uses his reduced value of life to put the cost of this event at $600 trillion – the same as the cost of a large asteroid strike because, from the perspective of human society, it is the same event: annihilation is annihilation. A more conventional value of life estimate, as for the asteroid, would increase the cost of this event 40 to 100 times, depending on how the wide variation of world wealth is reflected in the estimate.

Posner asserts that nothing is being spent to reduce this risk. This is somewhat unfair, since at least the cost of the assessments should be counted, and possibly the cost of a small delay in starting up the Brookhaven collider, but these are still very small numbers, perhaps of order $100,000 to a few million. Assuming, on the high side, that avoidance-related expenditures are $1 million per year during the accelerator's operating life, the implied maximum probability of this event is 1 in 600 million. Alternatively, if avoidance expenditures are actually zero, the implied probability is of course zero.

Here, however, the inverse cost-benefit heuristic is not particularly useful. Even ignoring the difficulty of assigning a monetary value to the obliteration of the Earth, the analysis of this risk turns on the balance between two other numbers, both of them profoundly squishy: the societal benefits of operating the collider, and the probability of the catastrophe.

Posner initially puts the benefits at $250 million per year of operation, then later reveals he believes the true value might be near zero or even negative. If only material economic benefits are counted, this range sounds plausible. Doubtless some would argue the number should be substantially higher – perhaps $1billion per year, not $250 million – but Posner's modified precautionary principle reminds us to be cautious about expansive estimates of material benefits, because even today's rich-world citizens may be well into the region of diminishing marginal benefits from consuming more and better stuff. In Posner's initial analysis, the collider's present-value cost is $1.7 billion, giving a net present-value benefit of $400 million if benefits are $250 million per year of operation. Estimating the annihilation risk at $500 million ($600 trillion cost if it happens, 10^{-7} probability per year,[6] summed over a 10-year operating lifetime and discounted at 3%) reduces the project's net present value to minus $100 million. But these numbers are all so labile that it is easy to make defensible changes in them to reverse the conclusion. If you, like Posner, think the social benefits of the facility small – after all, this research is

[6] This is Posner's interpolation between the two team's estimates, using an early draft of the Brookhaven study that put the middle estimate at 1 in 5 million, instead of the later revised 1 in 500,000.

remote from practical application and serves largely to indulge national pride and the intellectual passion of a tiny elite group – you only need reduce annual benefits from his $250 million to $200 million to conclude the collider should not be built, without even considering its risks. If you include the risk but use the upper-bound probability estimate of the CERN assessment, 1 in 500 million per year, the present-value of the risk is only $10 million, so the collider should be built provided its social benefits are at least $190 million per year. The risk could be further reduced to only $10,000 by using the smallest estimated upper-bound from the Brookhaven analysis. Eschewing loosely defined upper bounds in favor of best-guess point estimates could similarly reduce the weight of the catastrophe risk, while using more conventional value-of-life figures would increase it.

This project of blue-sky quantification does provide the salutary discipline of making you ask about the societal benefits of such a research facility, attempting to characterize the nature of the risks it poses, and affirming that the scientific enterprise – when it consumes vast public resources and imposes public risks – is legitimately subject to public control. But the project is likely to be of little help in bringing either increased rationality or increased tractability to making the decision, both because of the extreme malleability of the numbers and – crucially – because the only evident way to limit this risk is to close down or sharply restrict the associated areas of scientific research. Such a decision is not likely to turn on specific quantitative balancing of estimated risk and benefits, except to the extent that these are constructed after the fact to legitimize a decision already made on other grounds. Rather, it is likely to reflect a conflict between deeply conflicting ideas of desirable social goals – prudence and restraint, versus bold expansion in the pursuit of human knowledge and power.

The analysis of global climate change is also problematic, but for less fundamental reasons than the analysis of the strangelet scenario. Although Posner identifies inter-temporal tradeoffs as the deepest conceptual problem in assessing responses to climate change, he completely avoids this problem in his analysis, instead basing his conclusions on a series of *ad hoc* and relatively unsupported estimates of the costs and benefits of slowing climate change.

For impacts of climate change, he cites an estimate of $4 trillion present-value losses through 2105, based on a middle scenario of baseline emissions and climate sensitivity under which the Earth warms 2.4° C by 2105.[7] After criticizing this estimate as probably too low, he recasts it as an estimate of the impact of ***incremental*** climate change – not what the authors of the original estimate meant, since roughly half of their figure consisted of willingness to pay to avoid a 1% risk of a catastrophic impact (defined as 22 – 44 percent GDP loss) associated with this 2.4° C warming scenario. Having thus re-defined this estimate, Posner proceeds to deem it negligible, and on that basis argues that the entire standard range of projected warming by 2100, 1.4 to 5.8° C, can be neglected.

Instead, he argues that our response should be determined by risks of abrupt and potentially catastrophic climate change, whose effect he estimates as a permanent 20%

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[7] Nordhaus and Boyer (1999, 66). Posner also cites an estimate of $5 Trillion from Lomborg (2001, 310), but this is simply Lomborg's arbitrary adjustment of the same Nordhaus and Boyer estimate.

reduction of GDP (a figure so small that it is not clear how this risk passed his initial screening to be considered a catastrophe). Discounted at 3%, this represents a present-value loss of $67 trillion for the US. Comparing this to present US expenditures on climate change – a figure Posner mis-states by counting only the ~ $2 billion for climate-change science, not the ~ $3 billion for technology – his inverse cost-benefit heuristic suggests an annual probability for such catastrophic climate change as 1 in 39,000.[8] Revising this calculation to include the correct current expenditure and displace the occurrence of catastrophic climate change a few decades into the future would reduce this implied probability to about 1 in 10,000 per year. What is our best estimate of this probability? Several factors (e.g., increasing evidence of disruptions of major ice sheets and better characterization of past abrupt changes, as well as the expert surveys reported by Nordhaus (1994), Morgan and Keith (1995) and others) suggest it is more likely of order 1 in 1000 to several percent over this century – neatly bounding this corrected estimate of 1 in 10,000 per year. With the required corrections, Posner's conclusion is substantially weakened. Under the simple (and in this case, quite false) assumptions of risk neutrality and unit-elasticity risk reduction that underlie his inverse cost-benefit heuristic, present spending to limit this risk might be about right, or under the most conservative assumptions of catastrophic risk we might wish to spend up to 10 times more – if spending is the way to solve the problem.

But in moving past this conclusion to consider what should be done, Posner shifts even further away from his own analytic framework. His proposed response to climate change does not principally rely on public spending, but on regulation to motivate private efforts to develop new energy technologies and cut emissions. In this, having earlier rejected Nordhaus's estimates of climate impacts as too low, he proceeds to reject the corresponding quantitative estimates of mitigation costs without even a mention.

Rather, his proposal relies on a simple graphical analysis of the effects of a tax on greenhouse-gas emissions. He correctly frames the problem as motivating development over several decades of the energy technologies needed to move away from emitting sources, and argues for an emissions tax to achieve that. But his reasoning relies on a simple two-period model of market response to the tax, with an inelastic short-term response and a more elastic long-term response. The inelastic short-term response means that the tax introduces only small allocative inefficiency, while providing strong incentives for the research and innovation needed to reduce emissions in the long term, over which the response is assumed to be substantially more elastic.

There are no specifics about how big a "substantial" carbon tax would be, or how it would be structured, phased in, or varied over time. Moreover, the argument ignores a large literature on mitigation costs and their implications for the preferred stringency of mitigation policy. Emissions reductions are not free, and neither are the innovations that facilitate them, but these issues cannot be addressed in the framework of Posner's two simple response curves. Estimates of the cost of stabilizing the atmospheric content of greenhouse gases vary widely – e.g., from a few tenths of a percent to a few percent

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[8] An arithmetic error in the book reduces this probability by a factor of 10, to 1 in 388,000 (Tab 3.2, pg. 182).

present-value loss of future GDP to stabilize CO_2 at 550 ppm (double the pre-industrial concentration), a level often proposed as avoiding the worst risks of climate change (IPCC 2001b). These cost estimates are sensitive to the assumed path of emission growth without intervention, the ease of substitution in the economy, and how revenues raised by a carbon tax are recycled through the economy. Most important, mitigation costs depend strongly on assumptions about the conditions that drive innovation and technological change, which are not well modeled in current analyses, and characteristics of markets for research and development, which are not considered at all. Still, how much we want to reduce and how fast must depend on these costs, as well as on the distribution of climate-change impacts that can thereby be avoided, whether from incremental or abrupt change.

Finally, there is bioterrorism. Posner postulates that the upper-bound catastrophic attack would bring 100 million US deaths, for an estimated cost of $700 trillion ($7 million per life), which he raises to $1 quadrillion to account for collateral harms. Given present expenditures to reduce this threat of roughly $2 billion per year, his inverse cost-benefit heuristic gives a probability of 2 in a million per year. Well founded estimates of the probability of a catastrophic bioterrorist attack are not available, of course, but I would guess it to be much bigger than this, perhaps in the 10^{-2} to 10^{-4} range per year and so somewhat larger than that for acute climate change. Posner does not state his guess, but agrees that it is much bigger than 2 in a million and so concludes we should be doing more to avoid this risk, subject to the same qualifications that apply to all the risks about marginal versus total effects, and the effectiveness of risk-reduction measures.

But doing what? Even more than for the other risks, this analytic framework is unhelpful in evaluating responses and deciding what to do. Reducing this risk is not principally a matter of spending money. Rather, proposed responses include increased police resources and powers, increased security and control over certain areas of scientific research (E.g., who may engage in relevant areas of research? What elevated scrutiny must they accept into their affairs? How freely can the results of their research be communicated?), and broader limitation of civil liberties. Such measures are likely to be deeply contested, and the associated burdens and harms especially resistant to monetizing. Posner recognizes this, so without comment he abandons his analytic framework entirely and instead relies on other arguments specific to this risk.

In some points, his argument is quite compelling. Clearly, decisions what to do about this risk must reflect a balancing of liberty interests (both general liberties, and the freedom of scientific inquiry) against security interests. This debate has not been adequately engaged since the 2001 terrorist attacks that raised general concern about terrorism. Moreover, one can easily find scientists who too quickly presume that complete liberty of their enterprise (with the possible exception of acts of voluntary self-regulation, such as the 1975 Asilomar guidelines on recombinant DNA research) is a fundamental requirement of a free society, regardless of the consequences – a claim that has substantial and under-acknowledged elements of self-interest, and could well be false. Here is one point where Posner's perspective as a lawyer is helpful in cutting through potentially dangerous scientific vanity. He may even be correct, although his tone is unnecessarily contemptuous, that the inadequacy of this debate in part reflects the inability of civil-rights advocates to understand the gravity of the security threats at issue, or their unwillingness to consider the tradeoff. Indeed, they may not even recognize how much civil-rights interest there is in reducing the risk of catastrophic terrorist attack, because such an attack would surely be followed by restriction of liberties far more severe than anything presently being proposed or attempted.

But Posner's argument here is so one-sided that he neglects another pathology of current debate that is of potentially equal or even greater importance – that security advocates have also failed to show they respect civil liberties, or can be trusted to pursue security interests with due regard for minimizing encroachments on liberties. These issues have become so entrained in broader, ideologically charged conflicts that there has been no room for the considered balancing of legitimate contending values that Posner seeks. Such a debate would have to be informed by a sophisticated understanding of the effectiveness of various specific measures at reducing terrorism risk – requiring that, at least in important parts, the debate could not be fully public but would have to take place behind a security screen. This poses deep questions of how, or even whether, a process could be designed that allows serious regard for liberty interests as well as security ones. There appear to be no obvious answers to this. While I am sympathetic to Posner's conclusion that some enhancement of police powers and limitation of recently enjoyed civil and scientific liberties may be warranted, I am deeply skeptical about who to trust to take these decisions with competence, integrity, and respect for both sets of values.

Overall Assessment and Conclusions

Seeking to assess the book in Posner's own spirit – overlooking its many small flaws and irritations, and focusing on the large-scale argument – how does it stack up? Three of his broadest claims – that we face certain real risks with potentially catastrophic outcomes, that these do not get enough attention relative to their gravity, and that there is a good case for doing more than we are to respond to them – are all persuasively made. Merely introducing these, and noting the structural factors that impede clear recognition and response to them, are significant contributions. But Posner's program goes further than this, and as it does it becomes progressively weaker. The most important failings of the book are that it only develops the proposed common analytic framework as a sketch so rough as to be nearly useless, and that it does not make the case that the proposed framework gives common useful insights into how to respond to all these risks.

There are important differences among these risks, in their origins, their distributions of potential consequences, the proposed responses to them, and the factors determining a preferred response. Table 1 summarizes several of these potentially important differences. These risks do, of course, have in common a catastrophic upper limit, so considering them together generates an impressive level of shock and morbid fascination, but even in their catastrophic character there are important differences. Posner is not consistent in defining the threshold of a catastrophe, and the worst imaginable outcomes of these risks differ widely. The catastrophes considered range from 20% world GDP loss, through destruction of advanced civilization, to the destruction of all people, all complex life, or the Earth itself. (For what it's worth, my view is that the most salient breakpoint for defining "global catastrophe" is the destruction of advanced civilization, not the extermination of the remaining hungry bands.)

(Table 1 approximately here.)

Moreover, for some of these risks, particularly climate change and bioterrorism, the catastrophic tail might not be the most important part of the distribution. For any risk, it is the joint variation of probability and consequence that matters, not the mere existence of non-zero probability beyond some extreme threshold. The most obvious measure of severity is the contribution to expected losses, the integrated product of probability and consequence, for which the largest values may lie at intermediate outcomes for some of these risks – mild to moderate catastrophes, if you will. Merely having non-zero probability at some extremely destructive upper limit may not suffice to bring these under common analytic framework, or provide a consistent approach to assessing responses.

Posner recognizes the limits of his framework implicitly, since he makes little attempt to use it consistently across the four risks. The only piece he attempts to apply to all is the inverse cost-benefit heuristic, but even this he deploys inconsistently – applying it to widely and seemingly arbitrarily different degrees of catastrophe – and it provides only the most limited of insights: in each case, it merely demonstrates that we should be doing more, under highly restrictive assumptions and with no guidance regarding how much more or more of what.

Where then does the argument of the book leave us in terms of judging what to do about these four risks? Asteroid impacts – a natural hazard, albeit one that includes more extreme outcomes than any other – are once again the easiest of the four. The case for doing more is clear, and deciding what to do is a matter of efficiently allocating public expenditure for risk avoidance. The only difficulties in deciding on a response are the technical problem of choosing effective, low-cost measures, and the political problem of paying for what is clearly a global public good. No other social values than economical risk reduction are implicated. Posner's discussion of factors that obstruct clear thinking about such extreme risks is of obvious relevance, and he does a valuable service by raising the prominence of this risk.

Assessing the strangelet risk and deciding what to do about it are substantially more difficult, and this is only partly because the probability of the event is so poorly characterized. Because this issue makes us consider retreating from broad areas of scientific research, it also raises questions of grand scale and potentially great historical consequences. What risks are we willing to accept for the pursuit of knowledge? Note that it is not the application of knowledge that is at issue, which would be more readily monetized, for it is the act of investigation itself that makes the tiny risk of annihilation. Is gaining ever more fundamental knowledge – and the vision of future human civilization deploying ever-greater material power based upon this knowledge, expanding to colonize other planets and solar systems – one of the noblest human aspirations, or is it blasphemy (or is it something in between, perhaps irrelevant to human concerns)? Would choosing to limit scientific exploration on the basis of tiny risks signal a mature adoption of voluntary restraint and a turning of human endeavor toward the pursuit of justice, beauty, and spiritual exploration, or a return to the ascendancy of ignorance and superstition? These are judgments of what kind of society we want to be and want to become long after those making today's choices are dead. Individuals are likely to form these judgments based on deep and divergent emotional, moral, and spiritual commitments, but we do not get to choose individually: because of the scale of the research endeavor and the scale of the risks, the choice is inevitably collective.

Posner suggests that the choice is easy. This is true in terms of practical feasibility, since the scale and expense of the required research facilities brings the decision clearly under public control. Perhaps it is even easy to identify the preferred choice – e.g., if this case can somehow be narrowly delimited so it does not imply a broad historical choice between exploration and prudence. But Posner's flippant characterization of the factors favoring proceeding as a monetized value of material social benefits from the research fails to capture the essence of the problem. And it bears noting that the choices that have been made, both in America and Europe, are contrary to the choice he judges so obviously preferable. Relative to the profound differences at issue in these choices, Posner's calculations provide some help in framing the questions, but none at answering them.

Of the four risks, climate change is the one for which Posner's definition of a catastrophe raises the most problems. By the criteria Posner states at the outset for defining global catastrophes, it appears clear at first glance that climate change should not have been included at all. Virtually all scientific and public discussion of abrupt or catastrophic climate change – and perhaps the most important part of the distribution – concerns events that are extreme relative to the benign experience of the past few centuries, such as severe multi-decade droughts in water-constrained regions like the American west, multi-year spells of severe tropical cyclone seasons, or the centuries-long cold event famously used in the Pentagon's 2004 abrupt climate change scenario exercise (Schwartz and Randall 2003). But while any of these could be seriously disruptive, perhaps impoverishing for many people, they would likely fall far short of destroying advanced civilization. Rather, they are roughly consistent with the magnitude of effect Posner ascribes to catastrophic climate change, 20% GDP loss. Can we imagine worse? Sure, but even the people thinking seriously about abrupt climate change appear not to consider them (Schneider et al, 1998). Unless we can persuade ourselves that these further extremes are not just imaginable but plausible, climate change might be the odd risk out.

But wait a minute. Climate change is also the odd risk out because it has the most mature policy debate of any of these risks. There are two international treaties in force, targets and policies in place to reduce emissions in dozens of jurisdictions, and a massive scientific advisory process grinding out authoritative assessments every few years (Dessler and Parson 2006). The liberty to consider unlikely extremes, to toss out estimates of their probability and consequences that are plausible but indefensible (these are not contradictory) as Posner does so readily, may well be precluded by the social and political constraints on debate that come into play when decisions with real stakes are on the table. Official assessments of climate change have been dominated by conservative, well supported mean estimates and projections. They do not even give serious attention to sub-catastrophic extremes such as Posner considers, or even to the top quarter of the standard range of projected changes, despite decades of unchallenged exhortations that these less likely but more consequential possibilities matter more for decision-making than the means (Patt, 2006). The professional costs of discussing potential pathways that are more severe but unlikely, or even of being at the high end of the standard projection range, can be substantial. The existence of these pressures to ignore speculative risks calls into question my judgment above that climate does not belong because it lacks truly civilization-ending risks. After all, the catastrophic asteroid strikes and collider accidents we are discussing have probability estimates of 10^{-9} to 10^{-12} per year. Can we really not imagine a civilization-ending climate scenario at this tiny probability? Are we this certain that a Snowball Earth, or a Venusian inferno *cannot* happen? I doubt it. Ask a climate expert over a beer: I bet the response is that this is not the most important part of the distribution of climate consequences, but it's there.

Whether the focus is on moderate catastrophes or extreme ones – the 10^{-3} tail of serious disruption or the 10^{-6} tail of true global catastrophe – and certainly when the entire tail of the distribution is considered, a plausible case can be made, using simple heuristics like Posner's inverse cost-benefit analysis, that more should be done. But again, what? As for the other risks, deciding what to do requires going into more detail than these simple heuristics can provide. In contrast to the other risks considered, there is both an active debate on what should be done about climate change and a great deal of early policy in place, such that all the important questions lie at a level of specificity that Posner simply does not reach.

Just as asteroids are a natural hazard only bigger, climate change is a problem of environmental regulation, only bigger. Its resolution lies in choosing some level of public expenditure, and some form of regulation of private actors, to mobilize the research and investment needed to move the world energy system away from emitting sources, effectively and at minimum cost. Posner's call for a substantial emissions tax to motivate the required efforts is approximately right – although there are some respects in which an equivalent tradable-permit system would be preferable, and either instrument would have to be phased in gradually (but with a clear and credible commitment to future increases) to reduce premature capital abandonment. But this conclusion is neither new nor especially provocative, and it is so scant on essential specifics and so illegitimate in its supporting reasoning that it makes no contribution to the debate.

Like the strangelet risk, but unlike (or less like) the asteroid and climate risks, responding to the threat of bioterrorism raises deep choices of what kind of society we want. But rather than pitting a tiny immediate risk of annihilation against a long-term vision of society's commitment to knowledge and exploration, this choice puts into opposition two primary social values right now: security and liberty. The threat arises from the combination of specific types of scientific progress, and malevolent human agency that turns the results of that progress to destructive ends. But unlike the strangelet, the relevant scientific capabilities are cheap, widely dispersed, and tightly linked with beneficial applications. Because controlling the relevant knowledge is close to impossible, the principal means to reduce the risk lie in security restrictions on both scientific and general freedoms. Posner's general quantitative framework is no help in weighing these values, as he acknowledges. Rather, his recommendation depends on his intuition that the societal harm of restrictions on scientific and civil liberties is being greatly exaggerated by the champions of those liberties. Unfortunately, however, he resorts to disparaging these advocates for ignorance, naiveté, and special pleading, and appears not to recognize the symmetrical neglect of these liberties by champions of security, or the acute difficulty of developing a process that consider both sides fairly. His conclusion that we should make more efforts and accept more restrictions to reduce the risk of catastrophic terrorism may appear moderately persuasive: when the consequences get big enough, consequentialism looks more attractive. But his specific prescriptions treat the most important categories of resultant harm with little respect, and he omits them entirely from his accounting of the costs we are already bearing to manage this risk. Consequently, his argument once again does little to advance the debate.

Despite the variable persuasiveness of his specific proposals, Posner is correct that we face these risks and must decide what to do about them. Moreover, there are probably more of these coming. Asteroids may be the only natural hazard this big we face for a few billion years (let's hope so), but the other three risks are all driven in various ways by the advance of human science and its application, from which other potential mechanisms of destruction – new scientific accidents, new forms of environmental stress, and new opportunities for large-scale malice – are likely to flow. Consequently, guidance in how to think coherently about catastrophic-scale risks is urgently needed, both for these particular risks and for the others we may face in a few years or decades.

Posner advocates an approach based on cost-benefit analysis, with bold guesses for numbers not available. But he follows his own advice extremely unevenly, frequently abandoning his analytic framework for *ad hoc* arguments specific to the characteristics of each risk. In my view this is appropriate, given the disparate character of the risks and the responses they require. But what does it mean for the broad claim that all these risks can be adequately assessed in a cost-benefit framework? There are two possibilities: Posner might be wrong about the applicability of a cost-benefit approach to these risks, or he might merely have failed in his own application of the approach.

Could a more sustained and disciplined analysis of these risks in a cost-benefit framework adequately capture their important characteristics and provide useful guidance on how to respond to them? My own intuition is that it could for some of these risks, but not all. On the one hand, the mere fact of a risk having a catastrophic tail does not preclude the use of cost-benefit analysis. The extension of the approach to managing risks is well established, and it can accommodate various attitudes to extreme risks while providing salutary benefits of disciplined, structured assessment. So to the extent that the choices at issue involve pursuing public safety at acceptable cost, through cost-effective public expenditure and regulation – as appears to be largely the case for asteroids and climate change – the merit of a cost-benefit approach looks broadly persuasive.

On the other hand, the other two risks considered here appear to raise fundamental collective choices of what kind of society we want, which have no evident similarity to the provision of market goods and services except that they are things people care about. Deciding what to do about unavoidable risks from scientific research inevitably raises society's commitment to knowledge and exploration, just as deciding what to do about terrorism – biological or other forms – raises the commitment to an open society, individual liberties, and privacy. There is no possibility of decentralized individual choice in either case, since where catastrophic risks are concerned, we are all truly in the same boat. And while each case clearly requires some form of weighing and balancing of the contending values – and in each case one can readily construct extreme hypothetical scenarios to make the preferred choice go either way – the assignment and aggregation of individual monetary willingness to pay appears utterly inadequate as a representation of these contending values. One broad hint that this is the case comes from the fact that Posner does not even try to represent the choices in this way.

Despite incompleteness of argument and weakness of execution, this book does a real service to identify and describe these risks, to highlight the fact that they are not getting the attention they warrant, and to pull them together to support a call for more serious consideration. Moreover, it is particularly useful to have a prominent conservative thinker doing this. Posner's calls for more public expenditure and effort to manage catastrophic risks, regulation of the emissions contributing to global climate change, and establishment of new, powerful international organizations to monitor and enforce environmental agreements and to coordinate investigations and enforcement against potential bioterrorist threats, are all to the good. There is something to outrage everyone in his recommendations, and that is likely to be a useful spur to thought, even if Posner may be indulging some private fondness for being outrageous and unpredictable. But these are not the proposals of a conservative ideologue. Rather, they suggest a naïve faith in the ability of honest analytic efforts to give useful insight into even the end-of-the-world risks. He proposes – and models – a bold willingness to compare diverse social values, to attempt to quantify benefits and costs even when only the crudest estimates are defensible, and to consider the possibility that new circumstances may call for limits on values that have been considered sacrosanct. But this broad program fails: he does not make the case for the commonality of these risks, or for the general applicability of a cost-benefit framework in addressing them. Rather, the principal contribution of the book – and it is a worthy one – is to educate about these risks, and to use the shock value of treating them together to draw much needed attention to them.

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Table 1: Major Attributes of Four Catastrophic Risks.

Risk	P (Civilization-Ending Catastrophe) per Year	Is Even Worse Possible?	Cause	Relation of Sci-Tech Advance to Risk	Nature of Response	Challenges to Assessment
Asteroid	$10^{-7} – 10^{-8}$	Yes	Natural hazard	Cure	Public spending on monitoring and deflection	Straightforward
Strangelet	$< 10^{-5} – 10^{-12}$?	Yes	Scientific research	Direct Cause	Stop or restrict relevant scientific research (feasible)	Severe: Deep uncertainty re probability; What kind of society (long-run)?
Climate	$10^{-3} – 10^{-5}$?	???	Avoidable by-product of human numbers and prosperity	Cure and Indirect Cause	Regulation, Private and public spending on energy R&D and investment	Moderate: Present-future tradeoffs; distribution effects; partisan bias in cost estimates;
Bioterror	$10^{-2} – 10^{-4}$?	No??	Scientific progress + malicious human agency (need both)	Necessary Part of Cause, May Contribute to Cure	Restrict scientific freedom and general civil liberties (control of knowledge not feasible)	Severe: What kind of society (now)? Need assessment process that is both trusted and secret