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Catastrophes of the 21st Century

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Abstract

There are few ways to better display our ignorance than by speculating on the long-term future. At the same time, making wise decisions depends upon both anticipating an uncertain future and the limits of what we can know. This paper takes a broad look at global trends in place today, where they may be taking us, and the implications for thinking about catastrophes of the 21st century. I suggest three types of catastrophes lie ahead. *The familiar* – hazards that we have come to expect based on experience and knowledge, such as earthquakes and typhoons. *The emergent* – hazards that are the product of a complex, interconnected world, such as financial meltdowns, supply chain disruption and epidemics. *The extraordinary* -- hazards that may or may not be foreseen or foreseeable, but for which we are wholly unprepared, such as an asteroid impact, massive solar storm, or even fantastic scenarios found only in fiction, such as the consequences of contact with alien life. I will argue that our collective attention and expertise is, perhaps understandably, disproportionately focused on the familiar. The consequence, however, is a sort of intellectual myopia. We know more than we think about the familiar and less than we should about the emergent and the extraordinary. Yet our ability to deal with the hazards of the future likely depends much more on our ability to prepare for the emergent and the extraordinary.

Introduction: Inefficiencies in the Marketplace of Ideas

The discipline of economics has given us the idea of an "efficient market," for which Eugene Fama won the Nobel Prize in 2013. The efficient market hypothesis holds that a stock market trades at fair value on an exchange because if it reflects all available information in its price. An efficient market, by definition, cannot be outperformed by a stock picker, except through good luck. Analysts in fields as diverse as finance and baseball have shown that markets are often far from perfectly efficient, providing opportunities to improve upon decision making.

Long before Fama, philosopher John Stuart Mill proposed a metaphor which has come to be known as the "marketplace of ideas" which analogizes the competition of ideas to the economic marketplace (Gordon, 1997). In 1919, the chief justice of the US Supreme Court Oliver Wendell Holmes argued that "the best test of truth is the power of thought to get itself accepted in the competition of the market" (as quoted in Ingber, 1984). This perspective is quite comforting to the scholar who works where knowledge meets action. Engagement in a public battle of ideas leads to knowledge that is more robust, a closer approximation to "truth," and decision making will proceed on a more solid foundation.

Or so the argument goes.

The reality is somewhat different. Scholarship has shown that "truth" does not necessarily emerge from the marketplace of ideas. For instance, Redkal (2014) describes "messages presented in respectable scientific publications are, in fact, based on various forms of rumors. Some of these rumors appear so frequently, and in such complex, colorful, and entertaining ways that we can think of them as academic urban legends." Dan Kahan of Yale University has published an series of studies indicating that what people believe about facts is typically a reflection of identification (group, social, political etc.) rather than a careful assessment of knowledge (e.g., Kahan *et al*., 2011). The "marketplace of ideas" it turns out is far from efficient.

To the extent that competition in the marketplace of ideas leads to the acceptance of erroneous or false knowledge claims, we can say that this marketplace is inefficient. Often, the acceptance of such claims is of little consequence. If people, and even policy makers, do not know the difference between a molecule and an atom or they cannot place Moldova on a map, the world continues to function pretty well.

However, there are instances where acceptance of incorrect knowledge claims can be considerably more consequential, in particular with respect to expert decision making.

This short paper looks at prospective catastrophes of the 21st century, but not with the aim of prediction or anticipation of what specific perils may lay ahead. Rather the goal here is to question the efficiency of the marketplace of ideas with respect to potential catastrophes that lurk in the coming decades. I argue that while there are positive signs of a healthy marketplace of ideas, there is also a case to be made for some considerable inefficiency in that market place. Our horizon scanning should be accompanied by greater thoughtful reflection about such perspectives. Are we paying attention to what matters? What surprises might yet catch us unprepared?

An Initial Example

For the past 20 years or so I have worked in the area of the economic consequences of natural hazards such as floods, tropical cyclones and earthquakes. Our early work led us to conclude that even as the absolute economic costs of disasters were rising, the cost as a proportion of measures of societal wealth was not (e.g., Pielke, 1999; Pielke and Landsea, 1998). These findings appeared in studies from around the world for various phenomena (see e.g., Bouwer, 2011). In other words, the world has been getting richer faster than the economic damage from extreme events has increased. Consequently, the proportion of damage from extremes has decreased as a fraction of measures of global wealth.

This trend has continued globally. Figure 1 shows the global weather-related disaster losses as a proportion of global GDP from 1990 through present.[105] The first half of 2015 has unusually low losses as compared to recent decades.

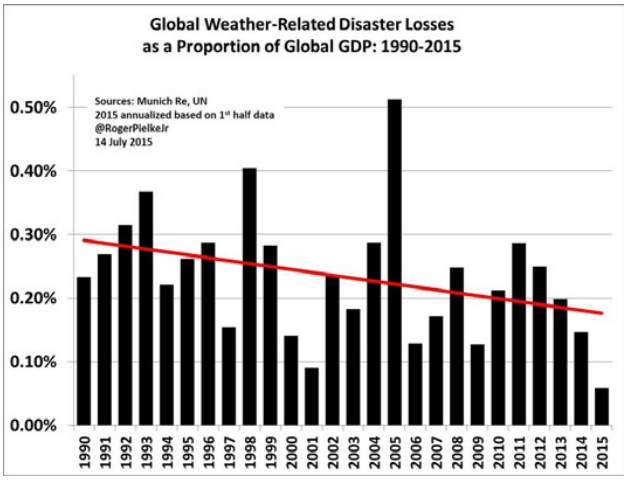


Figure 1.

Over 25 years the data show about a 40% decline in weather-related losses as a proportion of GDP (from about 0.30% in 1990 to 0.18% in 2015). It is important to point out that this trend is not predictive and is simply a characterization of the time series.[106] Further, because damage from extreme events reflects the interaction of the events and society, it would be unwise to use these data to suggest any conclusions with respect to trends or patterns in weather phenomena. To understand trends in weather one should always look at weather data.

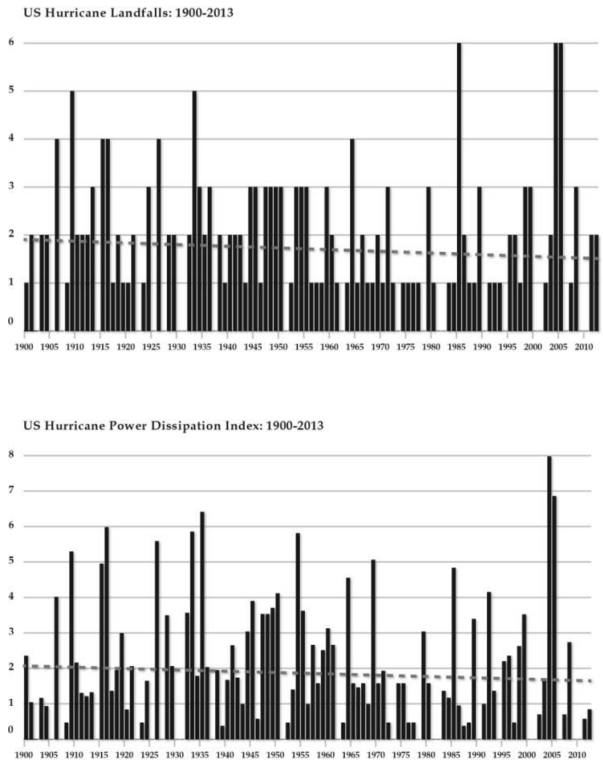
I have recently reviewed trends in weather phenomena that cause catastrophes, specifically tropical cyclones, floods, drought and tornadoes (see Pielke, 2014). That analysis concluded that there was exceedingly little evidence for an increase in the frequency or intensity of extreme weather events that cause the vast majority of property damage around the world. These conclusions are in line with those of the Intergovernmental Panel on Climate Change in its Fifth Assessment Report.

[105] The data, from Munich Re and the UN. 2015, are annualized based on first half year data. A similar trend is also present if geologic hazards such as earthquakes are included.

[106] For a more in depth analysis, with similar conclusions, see Mohleji and Pielke (2014).

The IPCC did identify increasing incidences of heat waves and occasions of heavy precipitation (but not floods), both linked to accumulating greenhouse gases in the atmosphere (IPCC, 2013).[107]

To provide just one example, US hurricanes account for more than 65% of all "global" losses in the Munich Re catalog of worldwide catastrophes. However, since 1900, the frequency and intensity of landfalling US hurricanes has actually *decreased* by ~20%, as shown in Figures 2a and b (data courtesy of NOAA). Figure 2a (top) shows the number of tropical cyclones at hurricane strength that struck the mainland United States 1900-2013. Figure 2b (bottom) shows a measure of the intensity of the storms (summed annually) at landfall.



Figures 2a and 2b.

The lack of any increase in the number US hurricanes or in their strength can also be observed in analyses of "normalized" US hurricane losses, which seeks to present an estimate of how much damage storms of the past would cause were they to hit with today's societal conditions. That is shown in Figure 3. Losses once adjusted for societal changes show no evidence of an increase. In fact, the United States (through at least mid-September 2015) experienced the longest period of time with no Florida hurricane or a major hurricane landfall. The US is in a remarkable stretch of good catastrophe luck.

[107] The absence of trends in certain extreme weather phenomena does not call into question the human role in a changing climate or the importance of the issue as a policy problem. See my book **The Climate Fix** for a full discussion.

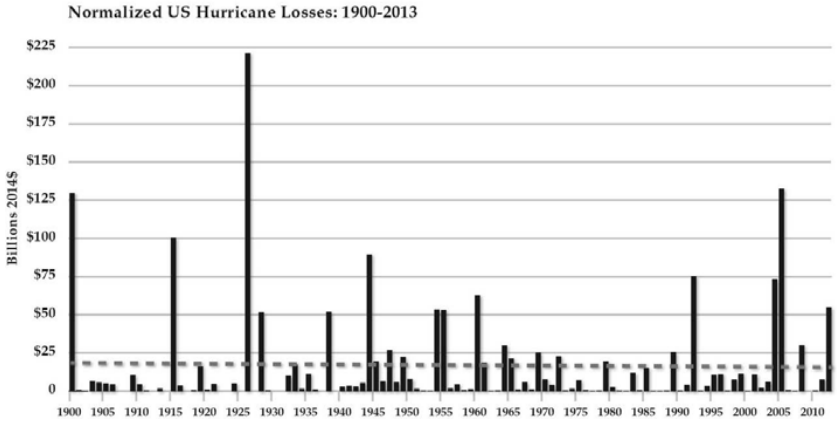


Figure 3.

Thus, the climatological and meteorological data provide independent, confirming perspectives. Hurricanes in the United States have not increased on time scales of more than a century. This is consistent with global data on both tropical cyclone landfalls and broader tropical cyclone incidence, whether or not a storm made landfall (Pielke, 2014).

Although evidence provides a compelling and consistent picture of trends in hurricanes, and indeed extreme weather more generally, such data have not been particularly welcome in the highly politicized public debate over climate change. The notion that extreme weather has been increasing, and hurricanes in particular, remains a fixture of the public debate.

For instance, Figure 4 shows the incidence of the phrase "extreme weather" on the pages of *The New York Times*, one of the leading US newspapers from 1965 to 2014. The use of the phrase skyrocketed over the recent decade, completely out of proportion with observed trends in weather events.

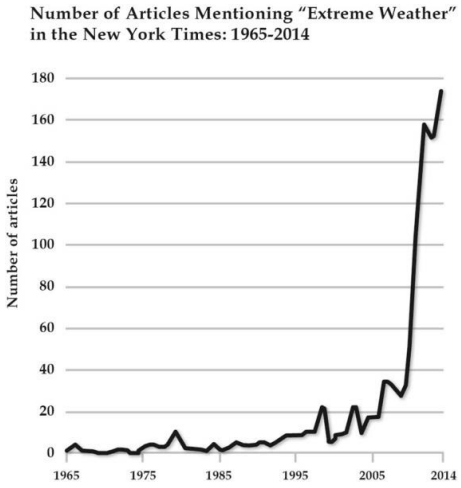


Figure 4.

The public discussion of climate change is not for the timid and I have long shared US President Harry Truman's view that those who can't take the heat should get out of the kitchen. In early 2015 I found the heat on me personally turned way up when a member of the US Congress decided to have me investigated for my research conclusions related to extreme weather. The Congressman explained that I was under investigation because, "His 2013 Senate testimony featured the claim, often repeated, that it is 'incorrect to associate the increasing costs of disasters with the emission of greenhouse gases.'"[108]

[108] https://theclimatefix.wordpress.com/2015/02/25/i-am-under-investigation/

I am a tenured full professor with a strong academic record, and used to the strange, sometimes vicious nature of the climate debate. So I weathered the storm. However, it also got me thinking. The fact that notable public discourse (such as in *The New York Times*) and policy maker perspectives (such as the member of the US Congress investigating me for accurately reporting on peer-reviewed science and the conclusions of the IPCC) differ so markedly from the evidential record suggests a profound inefficiency in the marketplace of ideas related to trends in extreme weather. Such inefficiencies might not matter in many contexts, but I have seen enough evidence that decision makers in government and business share these false understandings that it might actually influence policy responses to extreme events.[109]

I wondered if such inefficiencies might exist in less politicized, but far more consequential areas, such as perspectives on global catastrophes of the 21st century. What should we be worried about? And are we actually worrying in the right places?

Setting the Stage

The human race is on a roll.

Data show that many measures of things that people generally and overwhelmingly value are moving in a positive direction. This section of the paper reviews some of the long-term trends that have been observed as we move toward the middle decades of the 21st century. The past, of course, is not predictive. But a look at trends shows where we have come from, where we are today, and set the stage for a discussion of what might be in store for us in the years to come.

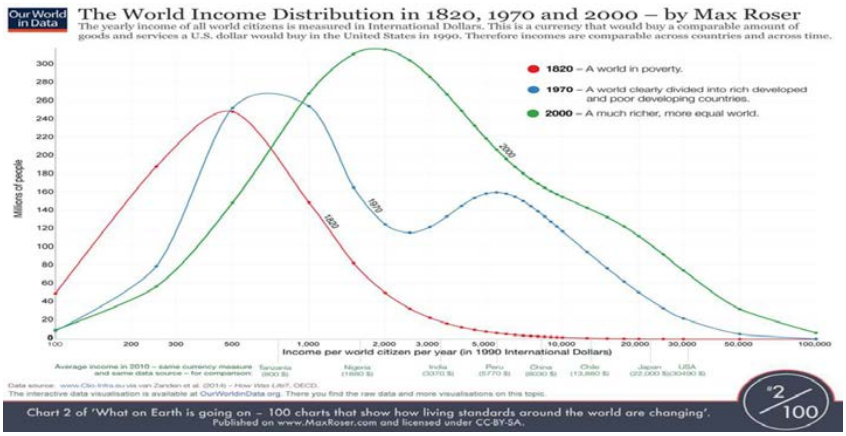


Figure 5: (OurWorldinData.org).

Figure 5 shows estimates of global income distribution.[110] Over the long term the world has become wealthier and less unequal. Much of the current debate over inequality focuses on income and wealth disparities within individual countries. Taking a broader, global view, inequality has decreased significantly between countries, a trend that is expected to continue.

We can look at wealth data in another useful way, and that is the proportion of people living in absolute poverty, generally defined in terms of an income threshold such as $1.00 per day (or similar). Figure 6 shows the remarkable decline in both the proportion of people living in absolute poverty and the absolute number. In 1970 there were about 7 people living in absolute poverty for every 1 who was not. By 2010 these numbers had almost reversed: for every 1 person living in absolute poverty 6 were not.

[109] For instance, in 2011 the *Sarasota Herald-Tribune* won a Pulitzer Prize, the most prestigious US journalism award, for its coverage of the problematic role of so-called "catastrophe models" in hurricane insurance and reinsurance. See http://www.pulitzer.org/citation/2011-Investigative-Reporting

[110] The graph is from www.ourworldindata.org by Max Roser.

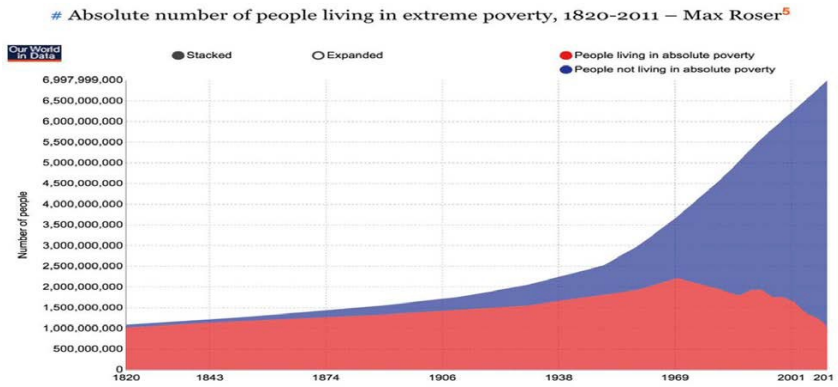
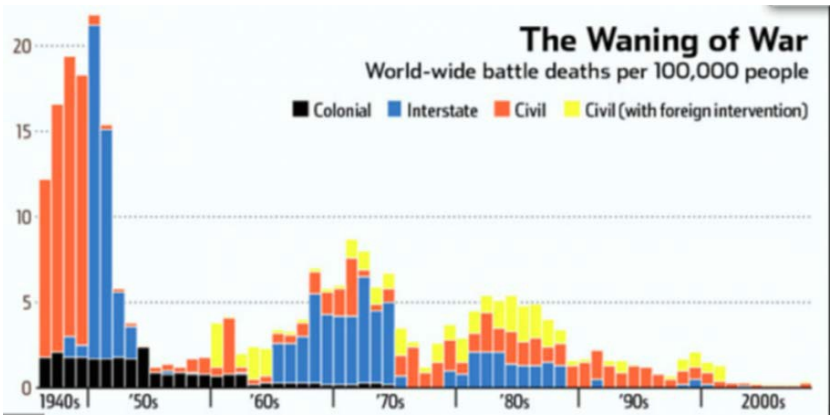
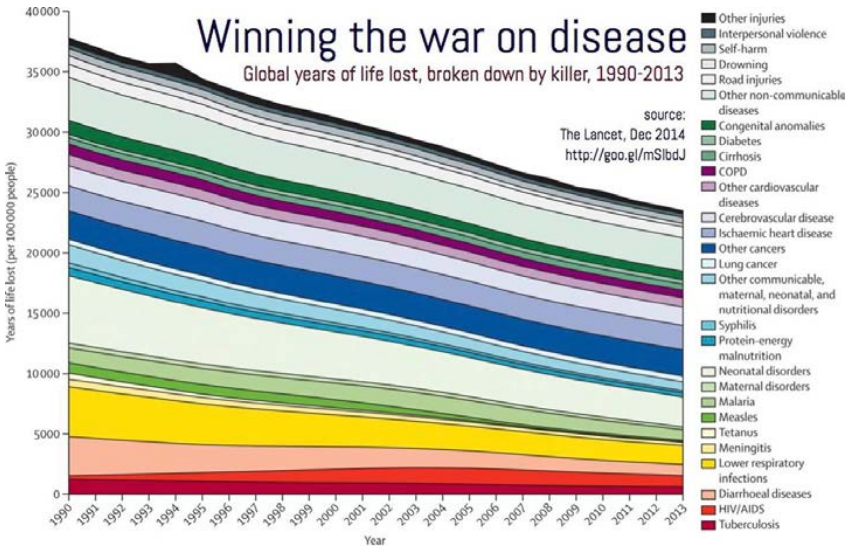


Figure 6: (OurWorldinData.org).

The massive accumulation of global wealth and its more equitable distribution is one of the remarkable success stories of my lifetime – the number of people living in absolute poverty has dropped by almost 50% since I was born. Because wealth often (but not always) serves as a proxy for other metrics of development, it should be no surprise that as global wealth has increased, disease and war have also decreased, as shown in Figures 7a and b.





Figures 7a and 7b (top: Stephen Pinker; bottom: The Lancet).

A complete review of global trends would of course be much broader and deeper than this brief overview. However, in addition to greater wealth and lower mortality, it is clear that the world is becoming older, on average, and its locus of economic activity is moving to the east at a rapid rate. The world has also become safer, on average. Food production has become more efficient, using less land, while the amount of food produced has more than kept pace with overall demand and population growth. Yet, some environmental indicators do provide reasons for worry, such as the accumulation of carbon dioxide in the atmosphere.

On balance, global trends certainly provide a basis for optimism about the future. But is that optimism warranted? What may lie ahead?

Crystal Ball Gazing

Prediction is a mugs game. This is particularly true when it comes to rare or unprecedented events resulting in catastrophe. However, horizon scanning to assess what might be possible is essential to preparing for an uncertain and unpredictable future. This section takes a look at three families of catastrophes that might occupy our attention into the 21st century. My focus is on our focus of attention. Are we allocating our intellectual resources in a way consistent with future threats? Or are there notable inefficiencies?

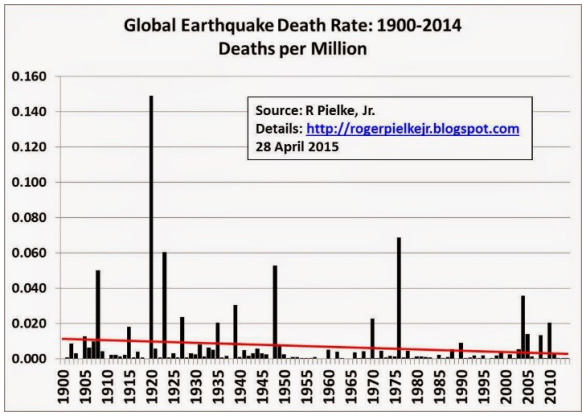
I suggest three types of catastrophes lie ahead. *The familiar* – hazards that we have come to expect based on experience and knowledge, such as earthquakes and typhoons. *The emergent* – hazards that are the product of a complex, interconnected world, such as financial meltdowns, supply chain disruption and epidemics. *The extraordinary* – hazards that may or may not be foreseen or foreseeable, but for which we are wholly unprepared, such as an asteroid impact, massive solar storm, or even fantastic scenarios found only in fiction, such as the consequences of contact with alien life. The following three sections consider each of these types of catastrophes in more depth.

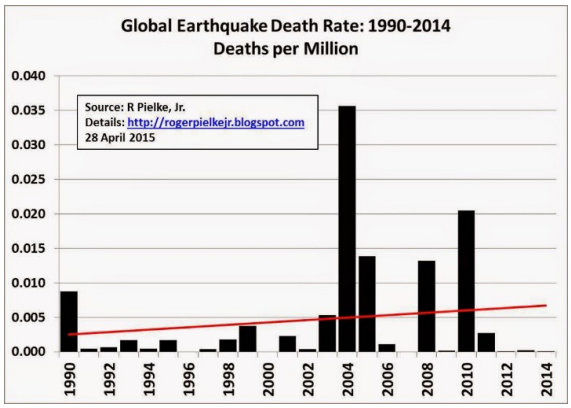
Familiar Catastrophes

Earthquakes, floods and tropical cyclones are extreme events to be sure, but they are also common place here on planet Earth. We have become familiar with these phenomena and developed, with varying degrees of success, ways to militate their impact. What might future such catastrophes look like? Here I suggest several perspectives based on history and trends in place today, looking at the case of earthquakes as an example of a familiar catastrophe.

There is significant variability in the occurrence of extreme events. On human time scales such variability may represent itself as an apparent trend of increasing or decreasing events. Consider earthquakes.

Figures 8a and b show the long-term global death rate from earthquakes since 1900 (left) and since 1990 (right), data updated from Daniell *et al*. (2011). Depending on your time frame you can legitimately argue that earthquake impacts are getting better (since 1900) or getting worse (since 1990).





Figures 8a and 8b.

The data show a longer term decline, but a more recent increase in catastrophe losses, measured as lives lost. These impact trends are consistent with trends (or variability, if you prefer) in earthquake incidence. Figure 9 shows the incidence of earthquakes greater than certain thresholds since 1900 (figure from Ben-Naim *et al*., 2013). The authors conclude that "Obvious increases in the global rate of large (M ≥ 7.0) earthquakes happened after 1992, 2010, and especially during the first quarter of 2014."

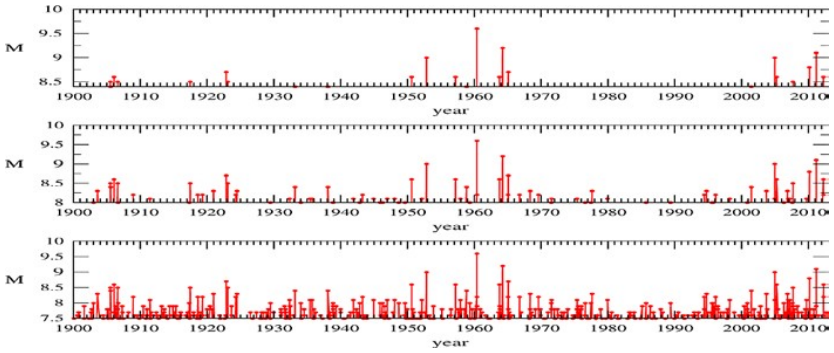


Figure 9: (Ben-Naim *et al*. 2013).

So it seems clear that the world is in a recent period of increased earthquake activity. But does that mean that earthquakes are increasing? Or is it that we are having a run of bad luck? Experts debate such questions, and the literature includes arguments on both sides. However one comes out on that debate, it also seems clear that to date, there is little evidence of any ability to skillfully anticipate global earthquake activity on decision making time scales. Further, irrespective of robust understandings of earthquake rates, knowledge of how to reduce their impacts when they do occur is well known, and is largely independent of incidence rates (Tucker, 2004). Yet, the possible locations for large earthquakes that could occur but have not in modern times is huge, meaning that there is a large gap between what is known about effective preparation and what has been implemented in locations prone to earthquake hazards, as has been learned in recent years in New Zealand, Nepal and Japan.

How big an impact could an earthquake have in the future?

To take one example, Vranes and Pielke (2009) looked at earthquakes of the United States from 1900 to 2005 and normalized their impacts to 2005 values. That is, the economic and causalities of past events were estimated for 2005 based on changing patterns of development and population. The 1906 San Francisco earthquake, the most damaging normalized US earthquake, normalized to 2005 values results in economic losses, on the high end, of more than $600 billion and more than 24,000 fatalities. This normalization is highly sensitive to assumptions, of course, but it does not require unreasonable assumptions to arrive at an estimate of a $1 trillion loss from such a quake (in 2015 dollars) were it to occur during the 21st century. One could envision a similar scenario for Tokyo, Istanbul, Manila, Delhi and other mega-cities around the world (Tucker, 2004).

The risks of familiar catastrophes such as earthquakes, and including many other types of natural hazards, are large, vary over time and are exacerbated by trends that are otherwise thought to be positive, such as growing urbanization and global wealth. At the same time, history has shown that such risks are manageable and we can demonstrate a track record of improvement with respect to economic losses and causalities. If we are smart, we'll continue to see these trends move in the right direction. Yet without a doubt the 21st century will see its share of notable catastrophes that will at once be tragic and utterly ordinary.

Emergent Catastrophes

Some catastrophes are difficult to place into historical context because there is really no such relevant context. Among them are financial crises, supply-chain disruption or epidemics.

For instance, Table 1 comes from Supply Chain Digest and shows (as of 2006) a ranking of top ten "supply chain disasters."[111] These are not disasters caused by extreme events like a flood (e.g., Bangkok 2011) or an earthquake (e.g., Honshu 2011) which then have knock-on effects to global supply chains, as important as these are. These disasters are caused by the failure of a system created by humans which displays some unanticipated behavior for which decision makers were unprepared.

Rank	Company	Year(s)	Issues/Problems	Impact/Result
1	Foxmeyer Drug	1996	New order management and distribution systems don't work and fulfillment cost targets build into contracts are also unattainable	Huge sales losses; Foxmeyer files for bankruptcy, and is eventually bought by McKesson
2	GM	1980s	CEO Robert Smith invests billions in robot technology that mostly doesn't work	Smith fired; Low tech Toyota uses lean manufacturing to gain strong competitive advantage as GM's market share heads south
3	WebVan	2001	On-line grocer has many problems, including massive investment in automated warehouses that drain capital and aren't justified by demand	Company goes from billions in market cap to bankrupt in a matter of months
4	Adidas	1996	New warehouse system - actually, first one then another – and DC automation just don't work	Company under-ships by 80% in January; incurs market share losses that persist for years
5	Denver Airport baggage handling system	1995	Complex, hugely expensive automated handling system never really works	Airport opens late; huge PR fiasco; system is only minimally used from start and shuttered totally in 2005
6	ToysRUs.com	1999	Can't fulfill thousands of order for which is promises delivery by Christmas	Famous "we're sorry" emails 2 days before Christmas cause firestorm of negative PR; eventually outsources fulfillment to Amazon.com
7	Hershey Foods	1999	Order management and warehouse implementation issues cause Hershey to miss critical Halloween shipments	Company says at least $150 million in revenue lost; profit drops 19%, and stock goes from $57 to $38

[111] http://www.scdigest.com/assets/press/06-01-27.php

Rank	Company	Year(s)	Issues/Problems	Impact/Result
8	Cisco	2001	Lacking adequate demand and inventory visibility, Cisco is caught with piles of product as demand slows	Company takes $2.2 billion inventory write-down; stock drops 50% and has stayed near that level since
9	Nike	2001	Trouble with new planning system causes inventory and orders woes	Nike blames software-related issues for $100 million dollar revenue shortfall for the quarter; stock drops 20%
10	Aris Isotoner	1994	Division of Sara Lee makes disastrous decision to move production from Manila to even lower cost countries; cost rise instead as quality plummets	Sales are cut by 50%; company goes from strong profit to big losses; Sara Lee soon sells Isotoner unit to Totes
11	Apple	1995	Playing a conservative inventory strategy, Apple is swamped with demand for new Power Macs and can't deliver the goods	Apple takes PR black eye and loses PC market share, which it never really recovers

Table 1: Top Supply Chain Disasters

An "emergent" phenomenon, according to one useful definition is "a large scale, group behavior of a system, which doesn't seem to have any clear explanation in terms of the system's constituent parts" (Darley, 1994; cf. Homer-Dixon *et al.*, 2015). In other words, you cannot describe the behavior of the system as simply the additive consequence of its elements – hence the notion of emergence. Emergent systems are "complex" in the sense that its behaviors are "the result of interactions between a large number of relatively simple parts, cannot be predicted simply from the rules of those underlying interactions" (Darley, 1994). Such interactions can be simulated but not generally predicted, by definition.

Due to their inherent unpredictability, emergent phenomena pose a particular challenge for the use of insurance as a tool of management. Insurance requires that risks be knowable, to some quantifiable degree, in the sense of being able to characterize their statistics of occurrence (e.g., Berliner, 1982). Emergent phenomena do not meet this criterion of insurability. This does not necessarily mean that insurance cannot be used as a response tool, but rather that any such reinsurance will probably need the backstop of a residual market (that is to say, a public backstop against losses larger than industry can or will insure, see Weinkle, 2015).

With respect to catastrophic risks, perhaps the ultimate irony is that efforts to quantify risk, as a mechanism of responding to risk, itself can lead to emergent phenomena with its own considerable risks. Consider the role of so-called "risk models" in finance and their role in the global financial crisis. Risk models can be valuable tools in the financial industry because they allow decision makers to evaluate the consequences of their assumptions in a rigorous manner. But there are two significant problems with their use in financial decision making.

One is that risk models break down in times of crisis. Well before the global financial crisis, Daníelsson (2002) observed that "The basic statistical properties of market data are not the same in crisis as they are during stable periods; therefore, most risk models provide very little guidance during crisis periods." The same models that make sophisticated financial instruments possible during normal times are virtually useless during times of crisis. They can also create emergent behaviors in financial markets.

A second problem is that the use of risk models encourages a herd mentality among firms. According to an Inspector General's report from the US Securities and Exchange Commission released September 25, 2008, "In times of market stress, trading dries up and reliable price information is difficult to obtain.

Models therefore become relatively more important than market price in times of market stress than in times when markets are liquid and trading actively. Such stressed circumstances force firms to rely more on models and less on markets for pricing and hedging purposes."[112] Daníelsson (2002) observes that the wide reliance on risk models to make decisions in a crisis can lead to perverse outcomes if "identical external regulatory risk constraints are imposed, regulatory demands may perversely lead to the amplification of the crisis by reducing liquidity." To have many large institutions making bad decisions with flawed information is not a recipe for financial stability.

Daníelsson (2008) cites a Lehmann Brothers' modeler commenting on model performance during the summer of 2007: "Events that models predicted would happen only once in 10,000 years happened every day for three days." As the financial crisis unfolded, decision makers suffered from having little experience in using the complex risk assessments. This was revealed dramatically during the spring of 2008, when the *Financial Times* reported that an error in a model used by Moody's, one of the world's most respected and widely utilized source for credit ratings, research and risk analysis, led to a far higher credit rating than was deserved by a particular complex derivative product. Upon learning of the error, Moody's adjusted the model to reflect the ratings error, rather than admit the initial mistake.[113] Because no one had any experience with the sophisticated financial product being modeled, the presence of the error in the rating virtually escaped notice in the marketplace. Efficient? Hardly.

Effective use of models of complex, emergent systems usually means treating them as one of many approaches to assessing risk. The Inspector General of the SEC recommended that the SEC be "more skeptical" of risk models and that firms be required to develop "informal plans" for scenarios that may not be found in their models. In other words, they should use models heuristically and not as comprehensive tools for assessing risks. This implies that the appropriate use of any risk model is contingent on the decision environment – useful in ordinary times, risky in times of crisis. The sets a rather high bar for their effective use, as the existence of a crisis may not be readily apparent.

Risk models are an important tool and no doubt here to stay as a fundamental part of our 21st century global financial system. But wisdom will be found in using them effectively. Daníelsson (2008) explained,

"The current crisis took everybody by surprise in spite of all the sophisticated models, all the stress testing, and all the numbers. The financial institutions that are surviving this crisis best are those with the best management, not those who relied on models to do the management's job. Risk models do have a valuable function in the risk management process so long as their limitations are recognized. They are useful in managing the risk in a particular trading desk, but not in capturing the risk of large divisions, not to mention the entire institution. For the supervisors the problem is even more complicated. They are concerned with systemic risk which means aggregating risk across the financial system. Relying on statistical models to produce such risk assessments is folly. We can get the numbers, but the numbers have no meaning."

The global financial crisis provides a perfect example of emergent risks and the challenges of preparing for them. More broadly, dealing with emergent phenomena requires attention to what is possible, rather than the probabilities of possibilities, and strategies of resilience, robustness and responsiveness.

Extraordinary Catastrophes

The third category of 21st catastrophes considered here are the extraordinary. Those hazards that may or may not be foreseen or foreseeable, but for which we are wholly unprepared, such as an asteroid impact, massive solar storm, or even fantastic scenarios found only in fiction, such as the consequences of contact with alien life. Perhaps surprisingly, such extraordinary hazards have received some attention in recent years.

For instance, Towers Watson has focused on a category of "extreme risks" which it defines as "potential events that are very unlikely to occur but that could have a significant impact on economic growth and asset returns, should they happen."[114] Towers Watson provided a ranking of what it concluded to be the top 15 "extreme" risks, listed in Table 2 (cf., Smil, 2008). The ranking was created

[112] http://www.sec.gov/about/offices/oig/reports/audits/2008/446-b.pdf

[113] http://www.ft.com/intl/cms/s/0/0c82561a-2697-11dd-9c95-000077b07658.html

[114] http://www.towerswatson.com/en-US/Insights/IC-Types/Survey-Research-Results/2013/10/Extreme-risks-2013

by a ranking system focused on likelihood, uncertainty, intensity and scope. The differences between the categories, and ultimate rankings are thus highly sensitive to what is determined to be likely (or not) and the events consequences, both of which are, of course, highly debatable.

Rank	Risk	Description
1	Food/water/energy crisis	A major shortfall in the supply of food/water/energy
2	Stagnation	A prolonged period of little or no economic growth
3	Global temperature change	Earth's climate tips into a less habitable state (hot or cold)
4	Depression	A deep trough in economic output with a massive increase in unemployment
5	Global trade collapse	A worldwide protectionist backlash against cross-border trade
6	Banking crisis	Banking activity halts due to a lack of liquidity
7	Sovereign default	Nonpayment by a major sovereign borrower
8	Currency crisis	Extreme movement between floating rates
9	Deflation	Goods and services prices fall for an extended period
10	Health progress backfire	Massive rise in morbidity or mental illness; antibiotic resistance
11	Nuclear contamination	A major nuclear disaster leading to large radioactivity release and lethal effects
12	Extreme longevity	Significant increase in life expectancy overwhelms support systems
13	Insurance crisis	Insolvency within the insurance sector
14	Terrorism	A major ideologically driven attack
15	Infrastructure failure	An interruption of a major infrastructure network

Table 2: Towers Watson: Extreme risk ranking – Top 15 risks.

In a somewhat similar exercise, Bostrom (2013) focuses on the concept of "existential risk" defined as "one that threatens the premature extinction of Earth-originating intelligent life or the permanent and drastic destruction of its potential for desirable future development." Included in this category are things like nanotechnology or artificial intelligence run amok, global pandemic, nuclear terrorism and extreme climate change. Sandberg and Bostrom (2008) surveyed experts and arrived at an estimate of a 19% probability that humanity goes extinct before 2100, a number that they caution to take "with a grain of salt."

Even while taking that "grain of salt" with respect the specific risk probabilities, the potential risks of large magnitude are nonetheless interesting. The experts that they surveyed provided median estimates of the likelihood of >1 billion deaths by 2100 for each of the following threats: molecular nanotech weapons (10%), superintelligent AI (5%), engineered pandemic (10%), nuclear war (10%), nanotech accident (1%), natural pandemic (5%), nuclear terrorism (1%). These values are remarkably high.

In another, similar exercise in 2015 the Global Challenges Foundation produced a list of 12 risks that threaten humanity.[115] They identify risks described as "infinite" meaning that they could pose an existential threat. There are of course less intense scenarios associated with these risks that do not rise to the level of existential. Table 3 shows these risks, ranked by the number of times that each appears in a 22 different "global challenge" surveys identified in the report.

[115] http://globalchallenges.org/publications/globalrisks/about-the-project/

Rank	Risk
21	Climate Change
18	Nuclear War
17	Pandemic
15	Biodiversity loss
14	Asteroid/Comet/Meteor, Volcano
13	Genetic Engineering, High Energy Physics, Nanotech, Resource Depletion
11	Artificial Intelligence, Chemical Pollution, Ecological Catastrophe
8	Biogeochem, Government Failure, Poverty, System Failure
7	Astronomic Explosion, Land Use & Land Cover Change
5	Biological Weapons, Chemical Weapons, Extraterrestrial, Reject Procreation
4	Computer Failure, EM Pulse, New Technology, Ozone Depletion
3	Dysgenics, Ocean Acidification
2	Interstellar Cloud
1	Atmosphere Aerosols, Phase Transition, Simulation, Unknown

Table 3: Number of times Global Challenges are included in surveys of global challenges.

Climate change is ranked most commonly, appearing in 21 out of the 22 surveys. By contrast, the impact of a near-earth object (asteroid, comet etc.) presents a risk which is straight-forward and over the longer- term, a certainty. However it appears in less than 2/3 of the risk surveys. NASA explains that the probabilities of a large impact are small (e.g., on average a 100m object is expected to hit the Earth once every 10,000 years) and with proper monitoring, the world would have several years advance notice of such an approaching object.[116]

The differential focus is highlighted by Bostrom (2013) who observes, "it is striking how little academic attention these issues have received compared to other topics that are less important." The Global Challenges foundation points to the fact that there are about 100 times as many academic articles on the "dung beetle" as there are on "human extinction." Bostrom (2013) suggests that one reason for the apparent disparity is that "the biggest existential risks are not amenable to plug-and-play scientific research methodologies." Most notably, they are not often amenable to meaningful prediction or risk quantification. Further, none of these issues are politicized in the sense that climate change is, which provides a demand for evermore studies to buttress ongoing policy debates. No one is debating the risks of an asteroid impact.

Google Scholar allows for a simple, quantitative investigation of the focus of academic attention on extraordinary catastrophes. The graph below shows a simple ratio of articles on "climate change" listed by Google Scholar to articles on "asteroid impact risk," "global pandemic," "super volcano," and "extraterrestrial life."[117] The differential is stark.

[116] http://neo.jpl.nasa.gov/neo/target.html

[117] Searches were performed without quotes.

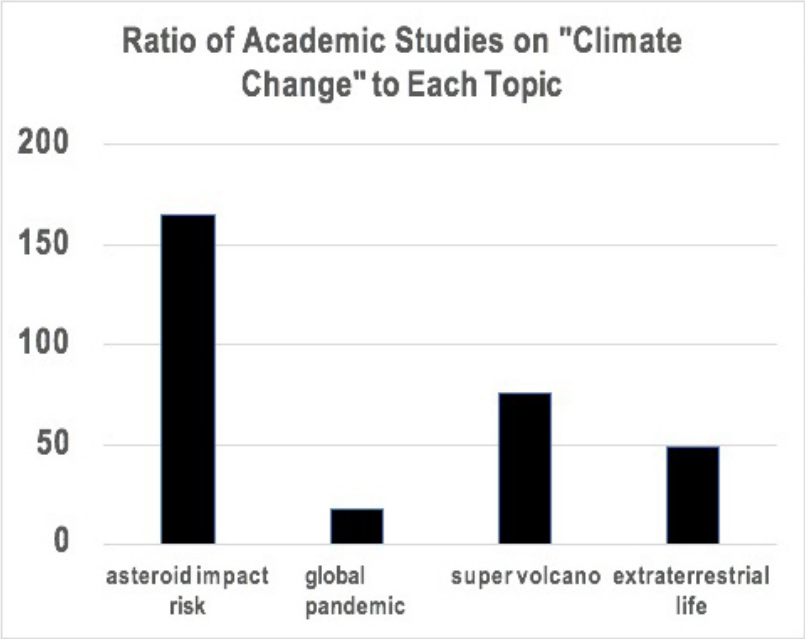


Figure 10.

The results confirm Bostrom (2013). For instance there are 165 times as many articles on climate change (>2.5 million) as there are on asteroid impact risk (15,700) and 18 times as many on climate change as on the subject of "global pandemic." Importance is, of course, a relative concept, and people will disagree as to the appropriate focus of attention among experts on these subjects. However, it is clear that our collective attention is focused on some topics far in exceedance to others.

For instance, there is little evidence that the scientific community has devoted much attention to the social, political and cultural implications of the discovery of extraterrestrial life, despite the fact that new resources are being devoted to searching for such evidence. When attention is focused on this topic it generally emphasizes the challenges of detection, but not its consequences for society. One notable exception was a discussion meeting held in 2010 by the Royal Society and a subsequent special journal issue on "The detection of extra-terrestrial life and the consequences for science and society."[118] If extraterrestrial life is indeed discovered might there be implications for the global market? For trade? For religion? For war? Are these questions even worth asking?

Politicians tend to stay away from talking about aliens (unless they are "illegal aliens") for obvious reasons. The United Nations briefly took up the issue of extraterrestrial life in 1977, but has let the issue lapse since then. Following the 2010 Royal Society meeting, the UN's Director of the Office for Outer Space Affairs, Mazlan Othman, categorically denied that she was the "the "take-me-to-your-leader person" if the Earth were to be contacted by alien life forms." It does sound a bit silly. But when pressed Othman "stressed that she did not know what role she would play."[119]

In fact, it seems unlikely that any policy makers in national or international settings have a clearly thought–through plan for responding to the discovery of extraterrestrial life, whether that be microbes on another body in our solar system or beady-eyed aliens looking to invade. The conversation is only silly if we assume that efforts to detect alien life will never succeed.

Good decision making typically involves exploring the consequences of uncertainties and areas of ignorance. Perhaps it is no surprise that the best treatments of the consequences of the discovery of alien life come from popular literature and Hollywood. Fiction and film can be essential for helping us to explore and discuss the consequences of technologies that don't exist or discoveries yet to occur. But they are not a complete substitute for a broader societal discussion. We are only surprised when

[118] http://rsta.royalsocietypublishing.org/content/369/1936.toc

[119] http://www.un.org/press/en/2010/101014_Othman.doc.htm

we fail to think about a possibility that actually occurs; there is little consequence to considering possibilities that go unrealized (cf., Rayner, 2102).

The 21st century is one in which science and technology are forcing many important conversations among experts and the public across civil society. Energy systems, agricultural technologies, diseases, unprecedented extreme events and disasters, terrorism, nuclear war between states, artificial intelligence, gene editing, synthetic biology … the list seems to have no end. Aon Benfield calls these "pear-shaped phenomena."[120] Given the certainty of ordinary and emergent catastrophes, should we also be talking about the societal and economic consequences of unlikely yet undesirable outcomes with respect to "pear-shaped phenomena"? The appropriate amount of research related to different types of catastrophes is itself something worth debating.

Conclusions

This paper has used the notion of inefficiencies in the "marketplace of ideas" to ask whether we are asking the right questions with respect to disasters of the 21st century. In conclusion, I suggest three hypotheses with respect to catastrophe risk and our state of knowledge.

1. The challenge of ordinary catastrophes is not generally one of knowledge creation, but knowledge application.

Earthquakes, tropical cyclones and the like are well-known phenomena. The actions that serve to foster safety and manage economic losses are also well known. In general, the challenge with respect to these types of events is to apply that which is known and shown to be successful. In the United States in 2005 Hurricane Katrina resulted in more than 1,000 deaths and $80 billion in losses despite hitting a vulnerable region, prone to extreme hurricanes in a wealthy nation with ample experience with such storms.

Overall, disaster costs worldwide have increased but at a rate slower than the overall accumulation of global wealth. Even under aggressive scenarios of climate change (such as proposed by the IPCC) a diminishing role for disaster losses (including earthquakes) might be expected. However, there is no guarantee of such outcomes and constant attention to disaster risk reduction will be necessary to secure the continuation of the positive trends in disaster losses observed over recent decades.

2. The challenge of emergent phenomena requires the application of mitigation strategies quite different than those typically used on the context of ordinary disasters.

Emergent phenomena, by definition, are generally unpredictable. Thus, strategies to prepare for catastrophes that emerge for interacting components of a system are likely to miss what matters. Simulation, scenario planning, robust decision making and resilient systems are key to an ability to effectively reduce the risks of emergent systems and to deal with crises as they emerge.

The response to the threat of Ebola in 2014 provides one example of a successful response to an emergent phenomenon. The combination of a terrifying, deadly disease and globalized travel networks meant that Ebola presented risks that appeared around the world, far from the actual location of the disease outbreak. The risks were not just medical but also social, as the disease created a considerable amount of fear, some justified by medical science, but much of it not. The WHO observed "What began as a health crisis snowballed into a humanitarian, social, economic and security crisis. In a world of radically increased interdependence, the consequences were felt globally."[121]

Dealing with Ebola, like SARS before it, was likely facilitated by the fact that the disease did not spread easily. Bill Gates (2015) has proposed a global warning and response system to help the world preparing for future pandemic risks. Such a system will require flexibility in response, because no one can anticipate exactly where the next pandemic threat might emerge. One infectious disease specialist explains of future pandemic risks that "second on the list is the one we haven't thought of, and at the

[120] http://thoughtleadership.aonbenfield.com/documents/201301_geomagnetic_storms.pdf

[121] http://www.who.int/csr/disease/ebola/one-year-report/response-in-2015/en/

very top is the one we can't imagine."[122] Dealing with emerging threats requires developing strategies to deal with risks that we aren't thinking of and may not even imagine.

3. The challenge of extraordinary catastrophes requires more attention to that which is largely outside our discussions of risk.

Vaclav Smil (2008), the polymath energy expert, writes that in contrast to the consequence of the accumulation of carbon dioxide in the atmosphere "all other unwelcome trends may come to be seen as unimportant." He writes that "it also may be that by 2050 we will find that global warming is a minor nuisance compared to something we are as yet unable to identify even as a remote threat." Consider that in 1960 the world had yet to gain awareness of the threats of chlorofluorocarbons to the ozone layer, the existence of AIDS or Ebola, and nanotechnology, genetic modification and artificial intelligence had yet to be created, except perhaps in science fiction.

Tomorrow's threats are unknown and perhaps unknowable. However, this need not stand in the way of a more expansive expert discussion about our collective ability to deal with possible futures. Some scenarios of undesirable futures are certainly imaginable, such as a global pandemic, an asteroid impact or nuclear war (whether inter-state or via terrorism). Expanding our discussions about how we might deal with such unlikely but possible catastrophes may ultimately help us to develop options for dealing with those threats which we are not presently imagining as possible. Organizations such as Towers Watson in the private sector and the Global Challenges Foundation have helpfully initiated such conversations. But we need more.

Ultimately, the one aspect of future catastrophes that experts may have the most ability to influence is the "marketplace of ideas." We may not be able to predict the future or to ensure that decision makers well use available information. However, we have no excuse for not providing information that might be helpful in supporting those decision makers in preparing for an uncertain future. That means expanding the scope of our view and correcting inefficiencies in the "marketplace of ideas" wherever we find them.

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[122] http://www.nature.com/news/how-to-beat-the-next-ebola-1.18114

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