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Risk management in a policy environment: The particular challenges associated with extreme risks

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ABSTRACT

This essay explores the ways in which understandings derived from approaches to general risk management in the policy environment provide a useful starting point for wider consideration of approaches to extreme risks. The findings are not the result of a research project, but draw on practice and reflection on risk management and strategic futures in central government in the UK over the last 15 years, with an emphasis on the role of the Government Chief Scientific Advisor and Government Office for Science.

From the perspective of a policy-maker, extreme risks are likely to be viewed initially through the lens of experience of risk in policy-making more generally. Approaches to the management of well-characterised risks in the context of civil emergencies show the importance of linking assessments of risk to the purpose of making the assessment, of communication and engagement, and of avoiding groupthink and narrow disciplinary discussions. In some cases where the risks cannot be well-characterised or easily imagined, new forms of visualisation and narrative, including futures work, can be used to shape and bound the risks and to engage policy-makers or citizens. Approaches to risk management in the context of innovation policy show the need to consider the risk of inaction as well as action, and the importance of path dependency.

1. Introduction

This essay considers lessons for those engaged in studying and communicating extreme risks, drawing from experience and reflection on the management of the full range of risks considered in the policy environment. There are two principal reasons why these lessons provide a good starting point for consideration of catastrophic risks. The first is that there are now many decades of practice and reflection on such risk management to draw from, and the second is that it is this more frequent experience of mainstream risks that strongly shapes the way decision-makers and publics initially engage with extreme risk.

2. Some ways in which science informs national risk management in the UK

2.1. The UK's National Risk Register

In the UK system of management of civil risks, national government is responsible for setting the frameworks for action by others, including the emergency services and local authorities.

"Risk management" here typically refers to reasonably well-defined risks, which materialise rapidly. Risk itself is defined as the harm multiplied by the likelihood of that harm. Every government department, like every major business and University, has a risk

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register that includes financial, operational, reputational risks. But the most visible and consistent expression of risk at national level is the National Risk Register (NRR), the result of systematic and regular exercises led by the Cabinet Office, to improve risk management and to provide a public resource for individuals and organisations wishing to be better prepared for emergencies (*The National Risk Register of Civil Emergencies*, 2015). Within the NRR the principal risks are summarised in a matrix of probability against impact. The identification and examination of the risks is informed by operational and scientific expertise, with the latter largely coordinated by the Government Chief Scientific Advisor (see Section 2.2).

Not all these risks have crystallised in living memory. For example, there has not been a major solar flare since the Carrington event in 1859. But in all cases of risks on the NRR the assessors either have access to historic records of the events or, in the case of risks such as major flooding, experience of smaller versions of the same type of risk. In preparing the Register, there are also discussions about the very long list of potential risks, some without human historical records, such as the effect of impact from a Near Earth Object.

Once risks get on to the Register, there is a system for ensuring responsibility for planning and acting to mitigate the risk. It helps that many of the actions – dealing with rubble, or loss of communications, for example – are common to risks with quite different causes.

So the purpose of defining and prioritising the risk is very definitely to inform action. And in the context of government at any level, the marginal spend or marginal moment of organisational focus on risk management is in competition with spend or focus on the very immediate, very visible, challenges and opportunities that are always present in the public sector. In some ways, this is the body politic mimicking the brain. A psychologist might simplify things by saying that our brains are not designed primarily to find out the truth about things but to keep us alive and that, although these purposes overlap they do not always align perfectly. So, in policy and implicitly in public discourse, the question of why we are discussing a risk matters greatly. The first questions a listener, whether a policy professional or a member of the public, are likely to be asking are “what does this mean for me, and what can I do about it”.

For deeply unfamiliar extreme risks this response poses a particular challenge. The best advice may be to conduct more research but, if it is the researchers themselves advising that, the advice will naturally be met with suspicion.

2.2. Science advice in civil emergencies

Since the 1940s, the British Prime Minister has had a Government Chief Scientific Advisor (GCSA) with the responsibility of ensuring good quality science advice across all disciplines. At present the GCSA reports to the Cabinet Secretary, and is supported by a small team of civil servants who form the Government Office for Science. The GCSA leads a network of departmental Chief Scientific Advisors (CSAs). Together and working through their wider academic and government networks they contribute to ensuring departmental and national risks are informed by scientific evidence. Those wider networks include formal advisory councils and committees and the national academies (Royal Society, British Academy, Royal Academy of Engineering and Academy of Medical Sciences). The academies operate in ways that range from rapid convening to independent and authoritative reviews of the science and scholarship relevant to policy challenges.

A COBR (Cabinet Office Briefing Rooms) Emergency Committee is established at a time of national civil emergency, to enable the government to deliver a coordinated and rapid response. It is chaired by the Prime Minister or relevant Cabinet Minister. As GCSA, Sir John Beddington introduced the arrangements known as SAGE (Scientific Advisory Group in Emergencies) (http://webarchive.nationalarchives.gov.uk/20130705045812/http:/www.bis.gov.uk/go-science/science-in-government/global-issues/civil-contingencies/role-of-sagehttp://webarchive.nationalarchives.gov.uk/20130705045812/http:/www.bis.gov.uk/go-science/science-in-government/global-issues/civil-contingencies/role-of-sage). SAGE supports COBR; it is chaired by the GCSA, who selects members to contribute the disciplinary mix needed for the specific emergency.

2.3. The Great East Japan Earthquake

To illustrate the SAGE mechanism in action with an example: in 2011, the Great East Japan Earthquake and tsunami struck, eventually resulting in more than 15,000 deaths. The outcome and responses beyond Japan affected, amongst many other things, the future of energy policy in Europe. At the start of the emergency, with the Fukushima Daiichi nuclear plant in a critical condition, the question from the Prime Minister to the then Government Chief Scientific Adviser (GCSA) was whether or not it was safe for British nationals to stay in Tokyo.

The UK’s response demonstrated many of the major elements of risk management, including drawing on multiple disciplines, being targeted to the decision-maker’s requirements, careful consideration of how to communicate uncertainty, and maintaining a focus on wider communication. The GCSA, Sir John Beddington, invoked the pre-arranged mechanism characterised as the SAGE (Scientific Advisory Group in Emergencies) and over a period of about 48 h or so gathered scientists from disciplines that included engineering, meteorology and health. They reviewed the available evidence and advised the COBR Committee on the balance of risks of people going or staying. Sir John also carried out telephone conferences, with open question and answer sessions, at Embassy locations to which Japanese officials were invited. Based on SAGE’s advice, the Prime Minister agreed there was no need to evacuate British Citizens outside the exclusion zone recommended by the Japanese government. In a classic demonstration of the way in which different policy decisions can be democratically arrived at on the basis of common scientific evidence, different countries made different choices about the safety of their citizens, in response to their different assessments of the risks.

A large part of the discussions amongst the experts was about how to describe the level of risk. Remember that there was little

time to refine or define, and the important point was communicating to non-scientists such as Ministers, who would in turn have to defend their decisions in the media. The experts ended up defining what they called the Reasonable Worst Case scenario. Choice of language is at the heart of the challenge of engaging policy-makers and publics with risk, both mundane and extreme. In this case some public perceptions of the risk were hovering between more familiar narratives of causality, experience and observation, and possibilities we can imagine (and which have been represented in fiction) that are consistent with the laws of physics, but which cannot be quantified and have not been experienced.

The Fukushima case study showed the vital importance of understanding public perceptions, and the wider context of a specific risk. As in other nuclear emergencies, the evidence was freighted with unavoidable perceptions aligning nuclear energy with "meltdowns", nuclear weapons and mass loss of life. One author states that the Fukushima incident is "extremely unlikely to result in a single death" (Thomas, 2011) directly from radioactivity, as does the IAEA's 2015 report. But some people outside Japan may at the time have associated the wider death toll with the nuclear emergency rather than the earthquake and the tsunami, and concern about the direct effects of radiation may sometimes deflect attention from the systemic effects such as displacement and effects on mental wellbeing. Such evidence does not lessen the immediate tragedies but it should alter our understandings about how such events are perceived and how best communicated, and demonstrates the importance of considering systemic effects as well as the probabilities of the immediate harms.

3. Developments in risk management with relevance to extreme risks

Building on research and practice, GCSAs and others have further developed aspects of risk management in ways that have potential bearing on consideration of extreme risks.

3.1. High impact low probability risks

The UK's formal national risk management processes are well developed compared to those of many other national governments. But there is further to go, and they continue to be developed. For example, the NRR does not consider the cascade or convergence or correlation of risks. Fukushima was an example of these, as the earthquake, tsunami and nuclear emergency could have been considered as independent risks. The NRR also cannot deal fully with High Impact Low Probability risks; a category which includes extreme risks.

Where the probabilities and nature of the risks are very hard to characterise it means the assessments need to be highly attuned to the difficulty for public decision-makers of weighing the costs of action in the case of a highly unquantified uncertainty, against those of more familiar opportunities and risks.

Under Sir John Beddington, the Government Office for Science reviewed government's approach to High Impact Low Probability (HILP) risk management processes on behalf of Cabinet Office (*Blackett Review of High Impact Low Probability Risks*, 2011). This report highlighted the way in which most HILP risks require cross-disciplinary insights: from the social and physical sciences, to statisticians, medics, engineers, lawyers and actuaries. It considered the ways in which insights from the behavioural sciences are essential. It noted that allowing analysis and debate to focus on moments of sudden and extreme risk will tend to shape the responses and may not allow for proper consideration of important systemic and long term effects, both in the definition of the risk and in the most effective management of it. Yet, at the same time, it noted that people and organisations will tend to ignore problems that are too complex to fit easily into current frameworks of accountability and behaviour.

There are significant extra difficulties if risks fall between or beyond traditional expert boundaries or traditional expert groupings and the report also pointed to the challenge to experts of speaking outside their comfort zones. For scientists it may be hard to deal with the situation in which, to caricature, any statement that is perfectly accurate is not useful, and any statement that is useful is not perfectly accurate.

There is a personal reputational risk to the expert of being seen to give credence to notions which challenge current technical or scientific understanding or lie outside normal situational awareness. And a direct asymmetry in that, in many cases, politicians are concerned with avoiding the error of having not acted when they should, while scientists may be more concerned with the error of reporting a finding where the finding is not robust.

The GO-Science report made a number of recommendations, including the need for government to go further to listen to external experts, and to develop opportunities for diverse thinking, testing and challenging assumptions. It also, and this may be particularly important for those thinking about catastrophic risk, highlighted the importance of looking for early warning signals, of including "near misses", and of considering linking or compounding risks.

3.2. Futures applied to risk management

The public and political default which creates the centre of gravity of analysis and decision-making, and of perception, is that the near future will be like recent past.

The UK Foresight programme, redesigned under the then Government Chief Scientific Advisor, Sir David King, in early 2000 has conducted futures work on topics from human enhancement and ageing, to flood risk (https://www.gov.uk/government/collections/foresight-projectshttps://www.gov.uk/government/collections/foresight-projects). The term "futures" here covers any investigation that includes explicit and rigorous consideration of future uncertainties. The most successful Foresight projects have often drawn on quantitative models, combining them with qualitative approaches and a focus on strong narratives and communications or – better

still – engagement with the target audience.

For example, the Foresight project on Future Flooding (2004) published graphics showing potential variations in flood risk across England and Wales in 2080. They show flood risk going up in some places under all of the selected scenarios. The models are based on major assumptions about long term economic and demographic growth, and extrapolated from global climate models to the UK. But as well as making the assumptions explicit in the technical analysis, the project allows the scenarios to draw attention to the overall, spatial and temporal uncertainties. The visualisation is inevitably powerful. To caricature: an MP looking at the maps will zoom straight in on their constituency; and a home owner will look for their home. Subsequent assessment of the project's impact included HM Treasury attributing to this evidence the decision significantly to increase the flood defence spend allocated to the Department of Environment, Rural Affairs and Agriculture at the next Spending Round. The project also contributed to wider debate around options such as giving land back to the sea rather than defending.

A somewhat similar approach, in a very different scientific and political frame, was Herman Kahn's controversial application of quantitative scenarios work in the 1950 and 60's as a way of foregrounding the potential consequences of use of nuclear weapons (Ghamari-Tabrizi, 2005).

Less dramatically, where trying to engage people with what is essentially understanding the dynamics of a system, either physical or socio-economic, serious games and playful models are extremely helpful. The Foresight project also used its underlying models to develop Flood Ranger, a science-based game: a simulation that put the player in charge of a vulnerable bit of the country. The player has to stay in power for a century. Playing the game required no technical knowledge, and it demonstrated the difficulties of balancing investment in economic growth, wellbeing and flood protection. It also showed that the same strategy had different outcomes depending on the climate pathway. Being a game, however, it still proved attractive, including to journalists who played it at the launch of the report. Versions were subsequently used by the Environment Agency to support engagement with local communities.

In a nearer term piece of work, a UK Foresight project contributed to effective management the systemic risk instabilities in financial markets. The NASDAQ "Flash Crash" of 2010 temporarily wiped a trillion dollars off the value of the market for several minutes and raised major concerns about the implications of computer-based High Frequency Trading for the stability of financial markets. The European Commission was reviewing the Markets in Financial Instruments Directive, with the aim of increasing market stability and efficiency, and including proposals aimed at regulating high frequency trading.

An urgent policy question was how best to reduce the risk of systemic failures in a technical and political context that was deeply uncertain. The interactions of human and algorithmic traders in the complex system that is a financial market raised significant questions about how regulation might affect outcomes. The Foresight project on the Future of Computer Trading in Financial Markets brought multiple disciplinary perspectives together to look 10 years ahead and engaged throughout with decision-makers, including members of the European Parliament. One of the Commission's draft proposals had been to introduce "minimum resting times" to slow down algorithmic trading. The project demonstrated that this proposed intervention could be expected to have a diametrically opposite effect to that intended, increasing the risk of instability rather than dampening it. The proposal was dropped.

3.3. Risks associated with innovation

In 2014, the Government Chief Scientific Advisor, Sir Mark Walport, published a review of the intertwined issues of innovation and risk (*Annual Report of the Government Chief Scientific Advisor*, 2014). The GCSA's *Innovation* report's aim was to help policymakers in dealing with the risks and benefits associated with innovations enabled by technology. It drew on a wide range of physical and social sciences and humanities and included a chapter on existential risk.

Innovation: Managing risk, not avoiding it discusses the importance of being reflective about what Sir Mark, perhaps drawing on his origins as a medical student, calls the lenses with which any debate can be viewed. In some senses the debates around, say, GM technologies for crops, or climate change, can get stuck in a frame in which the science is on trial and the level of proof implicitly being required is impossible to meet (and not required in other areas of risk management). This framing may then act as a distraction from debating other significant issues which are at stake.

An example is discussion of hydraulic fracturing for shale gas, where the Royal Society and Royal Academy of Engineering report on the physical and environmental risks provided evidence that was used to inform the government's decision to continue exploratory drilling in the UK (*Shale gas extraction in the UK*, 2012). It found that the health, safety and environmental risks can be managed effectively in the UK.

There remain hugely significant questions about fracking, when viewed through other lenses. One lens is the role of fracking in global carbon budgets and energy pricing and security. Another is a, local but important, lens through which amenity, landscape and the impact of thousands of lorry journeys must be considered. But these three lenses represent different framings, with overlapping but different stakeholder groups and with potentially different ranges of solutions.

The counterfactual is inevitably impossible to prove, but the report may have contributed to avoiding a situation where public debate was dominated by the images of "earthquakes in Blackpool" and flaring methane out of domestic taps. If so, it will have helped improve the quality of the public debate by keeping the focus on the issues where evidence and values are more contested and contestable, and where evidence and debate are needed to inform future decisions at local, national and international levels.

4. Insights for the management of extreme risk

This final section attempts to draw out further insights for those considering extreme risks and parts are inevitably more

speculative.

4.1. Challenging assumptions

Futures projects such as those in the UK Foresight programme inevitably challenge the assumptions of both policy-makers and scientists. A Foresight project on the future of Migration and Global Environmental Change looked forward to 2030 and 2060. It helped reframe some widespread assumptions about the scale and patterns of future international migration. In particular, it drew attention to the under-reported likely scale of "trapped" populations, whose lack of resources would prevent them from being able to migrate despite the pressure on them to do so.

This and other projects developed scenarios that stretched, but didn't break, the elastic of the audience's imagination: they were futuristic, but remained salient. One of the possible lessons for those considering extreme risks is that, where it is evidentially possible to do so, it may be more effective to attempt first to engage audiences with possibilities that might be considered plausible, rather than to allow the first framing of the risk to be one that is perceived as wholly implausible and capable of being rejected out of hand.

None of this quite gets at the heart of how we imagine wholly new possibilities or, more likely, get more mainstream attention paid to extreme imaginings that already exist. It seems to be more acceptable in some contexts to do this with objects rather than words, and to do it playfully rather than darkly.

While the role of synthesis of research findings remains key, the Government Office for Science, like others working in policy in the public sector, have begun to work with speculative design. For example, Foresight used design approaches as part of its recent project on the future of ageing, to generate ideas about the physical and social infrastructure future older people might want to see.

4.2. The role of narrative

One of the assumptions at the heart of public policy making is that the decision-maker must be able to justify a professional decision on the basis of a narrative describing actors and cause and effect, which is based on established models of how the relevant systems work, and preferably quantified. However, meaningful quantification is not always possible and in some instances a coherent and well-founded narrative is the best option.

For discussion of risks that cannot reasonably be quantified, the HILP Blackett report briefly looked at the narrative classification introduced by Ortwin Renn and others, which uses mythological characters. Renn uses Greek mythology systematically to characterise highly uncertain risks, especially those which science itself creates. He argues that the myths were developed at a period when Greek civilisation was shifting to settled agriculture and that there is a parallel with the 21st century in which we are moving from being a subject of nature to a partial creator of it.

So an extreme risk, such as some posed by potential applications of synthetic biology, might be characterised by Damocles (high potential for damage but very low probability of occurrence), or those posed by extreme weather exacerbated by climate change might be characterised by Cassandra. The thought experiment of a Minister on the Today programme or talking to HM Treasury colleagues and attempting to appeal to Greek mythology to describe a trade-off between attending to an extreme risk and attention being paid to healthcare or education, shows just how hard this kind of approach might be to apply in the media.

4.3. A diversion into the role of fiction

We know much more than we did a few decades ago about how individuals perceive risk and how it affects their decisions. By comparison there is relatively little accessible and codified knowledge or standard practice with respect to how societies talk to themselves over time about major emerging risks. In particular, while it is evidently the case that there is some interchange between accounts of evidence and narrative fiction, there is relatively little academic or practitioner exploration of this. What exists, comes from diverse fields. Obviously, these include futures studies (Raven & Elahi, 2015) but also authors, and scholars from other fields such as Ursula Heise's exploration of the narratives of species extinction and of the Anthropocene (Heise, 2016) or work by Bassett and Steinmueller (Bassett, Steinmueller, & Voss, 2012). The latter begins to delineate the ways in which fiction might influence the evolution of technologies in ways that include its role in reinforcing group identity amongst subsets of researchers or practitioners.

One hypothesis to consider for future research is that this relative lack of insight might matter particularly in the context of thinking about extreme risk, because of the difficulty of creating more evidence-based narratives leaves the public space to fiction – and therefore the effects of the gap are likely to matter even more than they may with respect to public discourse around other risks.

Fiction obviously gives shape to popular words and concepts at a time when our familiar language may be inadequate: from Frankenfoods, Big Brother, SkyNet and Terminator, to Minority Report. There is some suggestion it may inform the physical shape of new imaginings, as in NESTA's exploration of the timelines of writing by Douglas Adams and of the evolution of the ebook (Bland & Westlake, 2013).

Meanwhile, the Canadian author Margaret Atwood, reflects on speculative fiction as thought experiment (Atwood, 2011): helping to explore the potential consequences of proposed technologies in graphic ways by showing them as fully operational; helping readers interrogate potential effects on social organisation; and perhaps demonstrating the limits and potential of what it means to be human in very explicit ways.

Atwood has a particular interest in the historic locations of utopia which she suggests have been, variously, after death, the rim of the known world, underground, on other planets, in parallel universes, in a past so long ago it has been obliterated, or in the future. She suggests that, as we find out more about each place in question, the location moves to somewhere else. Maria Manuel Lisboa,

Professor of Portuguese Literature discusses apocalypses from Hieronymus Bosch and the Day of the Triffids to Genesis (Manual Lisboa, 2011). She points out that few utopias are actually particularly attractive and that in all but a few dystopic tales, some people survive: it is extremely hard to write, or at least to sell, a story in which all of humanity dies.

4.4. Path dependency

Section 2.3 included a brief discussion of the difficulty of ensuring systemic impacts are given full weight in public debate and decision-making, in the face of the more vivid accounts of sudden and disruptive risks. Similar challenges arise when considering the implications of the potential evolution of risks over time.

Examining more familiar risks, the GCSA's *Innovation* report argues that decision-makers should always consider the benefits and risk of not acting, even though most discourse is about the risk of action. The report suggests that, particularly in relatively "safe" societies with long life expectancy and low infant mortality, it can be possible to invert the benefit-disbenefit ratios. For example, the UK has not experienced significant food insecurity in recent times and this may colour the extent to which, in public discourse, it attends to the potential of some genetic technologies to contribute to enhanced security in global markets. Similarly, perceptions of the relative significance of various factors affecting the uses of vaccination may be coloured by the fact that the harm against which they guard is not one that the community has recently experienced.

The report also discusses the notion of accepting and engaging with multiple pathways over time. When technologies are at an early stage people typically ask who is developing it, for what purpose and with what values embedded. They discuss possibilities through analogy and metaphor. Such path dependency, discussion of context-specific uses and co-evolution of science, technology and applications, has the potential to matter greatly when considering risks from technologies at an early stage such as synthetic biology or AI.

The Royal Society's work on machine learning (*Machine Learning The Power and Promise of Computers that Learn by Example*, 2017) includes the results of structured public dialogue that demonstrates these general concerns. People ascribe very different social risk and social reward for different potential uses. The application of machine learning to health is reported high in both categories but to poetry writing is, perhaps sadly, low. For synthetic biology and for AI there is much to shape. What will the next uses be, who will create them and for what purpose? Who will benefit and who will be threatened? What will the emerging public narrative around the effect of AI and robotics on jobs mean for the evolution of the technologies?

In the UK stem cell technologies have been applied in ways that might not have been considered possible a decade or so, and which are not permitted in many other jurisdictions. At the core of the negotiation between the potential of the science and what is publicly desirable has been the Human Fertilisation and Embryology Authority (HFEA). The HFEA provides a long-standing and trusted place where highly expert scientists and practitioners engage with publics, with ethics and values. The history of stem cells and, in a very different way, of genetic technologies in plants, suggests that, where there are options sufficiently far developed to impact on people's lives rather than just their imaginations, it is essential to create right spaces for that kind of informed engagement.

The Royal Society and British Academy's recent report (*Data management and use: governance in the 21st century*, 2017) reviewing the framework for governance of data and the uses of data, including AI, aimed to connect debates and make proposals to ensure the UK and international groups have sufficient capacity for informed and visible debate and decision-making that is both rapid and capable of anticipation and foresight.

In engaging in debates on risks from technologies it is worth being aware of a pattern of narratives from history of science studies of emerging technology more generally. This pattern can be caricatured as an evolution of public narratives over time from concerns with utopia and dystopia to the more mundane "this is just a new way of doing things we have always done".

Those concerned about extreme risks choose to consider what might happen if the narrative were to be over-turned for the cases they study: in other words, that for some future case or cases, the pathway to eventual mundane accommodation by society of what was once a novel technology might not hold. To ensure the quality of the public conversation about such future uncertainties, it may be helpful to make explicit the possibility that it is necessary to overcome an implicit presumption the expression of concerns about extreme risk are simply manifestations of what will inevitably be a transient stage in the evolution of the narrative towards eventual accommodation of the technology.

Climate change represents an area of public policy where the interplay between science, assessments of future risk, perception and policy over decades is increasingly well studied. Some of the lessons from climate change may be very hard for those considering extreme risk to follow. For example major policy and behavioural changes appear to have depended upon the necessary (but possibly not sufficient) existence of sustained commitment to synthesising voluminous evidence, through the International Panel on Climate Change and related processes, keeping pace as the evidence, based on observations and modelling, evolves over time. There may be no equivalent paths open in areas of novel extreme risk.

Others lessons may be relevant in some contexts. For example, experience of communicating climate change suggests that to engage widely on a complex issue about the future it may be necessary to: concentrate on local impacts rather than global averages; make the debate about decisions (risks and their responses); have diverse forms of communication; make the issue salient which, in the case of climate includes considering the impacts on health and air quality; and to be very thoughtful about totemic words and numbers, especially those which carry different associations for different audiences, which include many commonly used terms such as uncertainty, and risk itself.

5. Conclusion: science, evidence and policy co-evolving

This essay finishes with some further examples of where science, evidence and policy have evolved together. These give, at the very least, proof of concept that even scientific issues freighted with value and risk can be considered and move forward.

One important strand is the way in which the science community reflects and responds. The emergence of new science itself changes the scientific agenda and becomes a source of meaningful questions for the same or different disciplines. Work by the Royal Society and many others has helped ensure that research on geo-engineering across disciplines is leading to phased insights. A similar pattern is reflected in the "web of protection" around biosecurity. The Society's project on machine learning in turn helped inform new research agendas in areas such as interpretability, or human-machine partnerships.

A second strand is the evidence that society does not have to be the victim of technological determinism or of existing views of human nature. There is a growing body of investigation into how major policy shifts – the introduction of Human Rights legislation, for example – take place and how evidence and scholarship, public debate, law, policy and practice intertwine. A study by the Institute of Government (*The S Factors*, 2011) found common patterns in areas where policy had changed over 20 or 40 years, to positions that would not have been considered possible at the start, such as smoking going from high status to being banned in public places, or the introduction of the UK's Climate Change Act with its statutory carbon budgets.

In many of these case studies, alongside the evolution and interplay of evidence, of science, of political, social and economic trends, there was another factor that seemed with hindsight to have made contributed significantly to changing opinions, policy and outcomes. Described in the Institute of Government report, and very relevant to the community deeply engaged with consideration of extreme risk: the conditions for success include the existence of a coalition of people who care about the issues, who are insightful and rigorous, who cross the boundaries between disciplines and sectors, and who are persistent. In Margaret Mead's words: "never doubt that a small group of thoughtful, committed citizens can change the world; indeed, it's the only thing that ever has."

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