



Working Paper Series

SWPS 2014-24

November, 2014

Towards Innovation Democracy?
Participation, Responsibility and Precaution
in Innovation Governance

Andy Stirling

SPRU Working Paper Series

The SPRU Working Paper Series aims to accelerate the public availability of the research undertaken by SPRU-associated people of all categories, and exceptionally, other research that is of considerable interest within SPRU. It presents research results that in whole or part are suitable for submission to a refereed journal, to a sponsor, to a major conference or to the editor of a book. Our intention is to provide access to early copies of SPRU research.

Editors

Tommaso Ciarli
Daniele Rotolo

Contact

T.Ciarli@sussex.ac.uk
D.Rotolo@sussex.ac.uk

Associate Editors

Florian Kern

Area

Energy

F.Kern@sussex.ac.uk

Paul Nightingale

Science, & Technology Policy

P.Nightingale@sussex.ac.uk

Matias Ramirez

Development

Matias.Ramirez@sussex.ac.uk

Joe Tidd &
Carlos Sato

Technology Innovation Management

J.Tidd@sussex.ac.uk
C.E.Y.Sato@sussex.ac.uk

Maria Savona &
Mariana Mazzucato

Economics of Technological Change

M.Savona@sussex.ac.uk
M.Mazzucato@sussex.ac.uk

Andrew Stirling

Transitions

A.C.Stirling@sussex.ac.uk

Caitriona McLeish

Civil military interface

C.A.McLeish@sussex.ac.uk

Disclaimer

The works available here are the responsibility of the individual author(s) and do not necessarily represent the views of other SPRU researchers. As matters of policy and practice, SPRU does not endorse individual research contributions.

Guidelines for authors

Papers shall be submitted in pdf or Word format. They should contain a title, an abstract, and keywords. Papers should be submitted to one of the Editors, who will process them and send them to the appropriate Associate Editor. Two members of SPRU will be asked to provide a short written review within three weeks. The revised versions of the paper, together with a reply to the reviewers, should be sent to the Associate Editor, who will propose to the Editors its publication on the series. When submitting the authors should indicate if the paper has already undergone peer-reviewing, in which case the Associate Editors may decide to skip internal review process.

Website

SWPS: www.sussex.ac.uk/spru/research/swps

IDEAS: ideas.repec.org/s/sru/ssewps.html

Towards innovation democracy?

participation, responsibility and precaution in innovation governance

Andy Stirling (SPRU and STEPS Centre, University of Sussex)

Fully referenced version of Chapter 4 at pp.49-62 in Annual Report of the Government Chief Scientific Adviser 2014. *Innovation: Managing Risk, Not Avoiding It. Evidence and Case Studies*. Government Office of Science, London. At: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/376505/14-1190b-innovation-managing-risk-evidence.pdf

November 2014

Abstract

Innovation is about more than technological invention. It involves change of many kinds: cultural, organisational and behavioural as well as technological. And there are no guarantees that any particular realised innovation will necessarily be positive. Accordingly, innovation is not a one-track race to the future. Indeed, it is not so much about optimizing a single trajectory, as it is a collaborative process for exploring diverse pathways. So, in order to realise the enormous progressive potential of particular kinds of innovation, what is needed is a more realistic, rational and vibrant 'innovation democracy'.

Yet conventional innovation policy and regulation tend simply to assume that whatever products or technologies are most energetically advanced, are in some way self-evidently beneficial. Scrutiny tends only to be through narrow forms of quantitative 'risk assessment' – often addressing innovation pathways at a time too late for significant change. Attention is directed only in circumscribed ways at the *pace* of innovation and whether risks are 'tolerable'. The result is a serious neglect for the crucial issue of the *direction* of innovation in any given area – and increased vulnerability to various kinds of 'lock in'.

These patterns show up across all sectors. Beyond GM crops, for example, there exist many other innovations for improving global food sustainability. But the relatively low potential for commercial benefits often leave many promising options seriously neglected. And this 'closing down' of innovation is intensified by deliberate exercise of powerful interests at the earliest stages. For instance, official statistics often conceal the extent to which patterns of support are concentrated in favour of particular innovation pathways. And where uncertainties are side-lined, even scientific evidence itself can carry the imprint of vested interests. Yet these effects of power remain unacknowledged in policy making. Policy is stated simply as 'pro-innovation' – a self-evident technical (rather than political) matter.

To address these challenges, innovation policy should more explicitly and transparently acknowledge the inherently political nature of the interests and motivations driving contending pathways. Here, this paper explores the potential for three emerging bodies of practice, relevant across all areas: participation, responsibility and precaution. Each involves a range of practical methods and new institutions. Precaution in particular is a subject of much misunderstanding and mischief. Among other qualities, this offers a crucial guard against the error of treating the absence of evidence of harm as evidence of absence of harm – and highlights the importance of wider human and environmental values.

Together, qualities of participation, responsibility and precaution extend scrutiny beyond anticipated consequences alone, to also interrogate the driving purposes of innovation. They allow societies to exercise agency not only over the rate and riskiness of innovation, but also over its direction. And they offer means to enable hitherto more distributed and marginal forms of innovation – which presently manage only rarely (like renewable energy or ecological farming) to struggle to major global scale. Together, these qualities celebrate that innovation is not a matter of fear-driven technical imperatives, but of a democratic politics of contending hopes.

1: The Breadth and Diversity of Innovation

Innovation is not just about technological inventions. It encompasses all the many ways of furthering human wellbeing. This includes improved production and use of goods or services in firms and other organisations¹. But it also includes new practices and relations in communities, households and the workplace². Advanced science and technological research can help drive and enable innovation³. Yet many other new forms of knowledge and action are also important⁴. Innovation can be created and guided by social venturing⁵ and mobilisation⁵ as much as commercial entrepreneurialism⁶. So grassroots movements⁷, civil society⁸, creative arts⁹, and wider culture¹⁰ feature alongside small business, service industries¹¹ and the public sector¹² in being as important for innovation as universities, research labs and high-tech companies.

Of course, there are no guarantees that any particular innovation in any of these areas will necessarily be positive. To take extreme examples that most may agree on, new forms of torture¹³, financial fraud¹⁴ or weapons of mass destruction^{15,16,17,18,19,20} are all active areas for innovation that might be judged to be generally negative. For other kinds of innovation, the picture is varyingly ambiguous. But it is rare that any given innovation is entirely, unconditionally or self-evidently positive²¹. And judgements are always relative. So, the unqualified claim in the current British Government slogan – “*innovation is Great... Britain*”²² – is not automatically true. Like other prevailing high-level talk of ‘pro-innovation’ policy – for instance, around the European Union’s ‘Innovation Union’ strategy^{23,24,25} – this misses the crucial point that the most important queries are about ‘which innovation?’. Whether or not any given innovation is preferable on balance to alternatives – let alone unreservedly ‘good’, still less “*great*” – is not just a technical issue. It is also a fundamentally political question. This means that even quite detailed aspects of innovation policy are legitimate matters for democracy^{26–32}.

In these widest of senses, however, well-conceived innovations can undoubtedly offer important aids not only to economic productivity³³, but also to enhancing many kinds of human flourishing or the public good³⁴. And this need not be a bone of contention, even under the most critical views³⁵. The more ambitious the aspirations to progressive social change, the greater the need for broad, diverse (and carefully scrutinised) kinds of innovation^{36 37}. An example lies in the imperatives for transformations towards a more Sustainable³⁸, equitable, healthy and peaceful world. Whatever forms these possible futures are held to take, they require radical kinds of innovation in the widest of senses³⁹.

Some innovation opportunities can be effectively addressed by well-governed fair and efficient markets⁴⁰. So, one important role for innovation policy lies in helping to foster commercial innovation in the public interest⁴¹. But not all benefits, risks or impacts are restricted to those private actors typically most directly involved in steering business innovation⁴². Established understandings, motivations and incentives driving the most powerful market actors, often fail fully to prioritise wider relevant social values and interests⁴³. In areas like health, agriculture, energy, environment, water, mobility, security, waste and housing, many of the least privileged (most vulnerable) people around the world are disproportionately excluded from conventional global patterns of innovation⁴⁴. Nor (as

we shall see below) are many important forms of uncertainty and ambiguity always fully or appropriately addressed by relatively narrow market-based signals or official statistics⁴⁵.

Depending on the context, then, market processes alone do not necessarily drive the best orientations for the kinds of innovation that are most needed from broader social viewpoints. This is true both across different domains of policy as well as within any given sector. For instance, the single largest area for public expenditure on research and innovation – in the UK as worldwide – is military^{46 47}. Innovation towards less violent means for conflict resolution are relatively neglected^{48 49 50}. Likewise, the most strongly-pursued energy options are those that offer greatest returns on established infrastructures and supply chains, rather than new distributed forms of renewable power or energy services^{51 52 53 54}. For its part, biomedical research tends to focus more on health disorders of the rich than the poor, and on therapeutics rather than prevention⁵⁵. This is especially so in speculative (but potentially lucrative) new areas like ‘human enhancement’ and ‘life extension’^{56 57 58}, with the Royal Society raising particular questions about patterns of prioritisation in neuroscience⁵⁹. Consequently, there are important roles for public policy in helping to prioritise across sectors, as well as encourage and support appropriate scales and directions for innovation within particular areas. And (as we shall see later), public policy is also crucial in helping to address the many uncertainties and ambiguities – by promoting greater analysis, deliberation and political accountability⁶⁰.

In nurturing these qualities, public policy can also fulfil other significant roles. Alongside higher education, business and civil society, government policy can do much to promote the knowledges, capabilities and environments that best facilitate socially effective innovation⁶¹. So, the more demanding the challenges for innovation (like poverty, ill health or environmental damage), the greater becomes the importance of effective policy^{62 63}. These challenges of innovation policy go well beyond simplistic notions of governments trying to “pick winners”^{64 65}. In any case, imperfect or self-serving foresight does not exclusively afflict the public sector, but also applies to powerful market actors⁶⁶. Though manifest differently, essentially similar degrees of uncertainty, intractability and deficiency are equally experienced in government, business and civil society⁶⁷. Instead then, the central challenge in innovation policy is about helping to harness the differences⁶⁸. This is about culturing the most fruitfully cross-fertilising conditions across society as a whole, for collectively seeding and selecting across many alternative possibilities and together nurturing the most potentially fruitful³⁹. This involves collaboratively deliberating, negotiating and constructing what ‘winning’ even means, not just how best to achieve it. These are the questions on which this paper will focus.

2: Policy and the Politics of Choice

The most important (but neglected⁶⁹) issue here, is that innovation of all kinds in any given area is not a one-track race to the future⁷⁰. Instead, it is about social choices across a variety of continually branching alternative pathways for change⁷¹. In this sense, innovation is more like an evolutionary process than a race^{72 73}. It is as much about exploring a space of different possibilities, as optimising any one⁷⁴⁻⁷⁶. As already mentioned, it is rarely self-evident – and often hotly contested – what should count as the most ‘desirable’ directions for discovery. This is true, for instance, of particular domains like Sustainable agriculture, zero carbon energy services or clinical and preventive responses to improving public health. In all these areas, there unfold many radically contrasting alternative pathways for innovation. Two of the most pervasively important qualities in choosing which pathways to prioritise, are therefore: (i) attending fairly to a **diversity** of possible directions and strategies⁷⁷; and (ii) including a **plurality** of perspectives in appraising any one⁷⁸⁻⁸⁰.

Consequently, it is not only important that innovation be efficient and competitive in any particular direction. It is also crucial equally for economic and wider social wellbeing, that the directions that are prioritised for innovation, are as robustly deliberated, accountable and legitimate as possible⁸¹. An economy that fails to do this, exposes itself to the risk that it will become committed to inferior innovation pathways, that other more responsibly and responsively steered economies may avoid. In other words, innovation may “go forward” quickly, but in the wrong directions.

History presents plenty of examples of innovation trajectories that later proved to be misguided – for instance involving asbestos, benzene, thalidomide, dioxins, lead in petrol, tobacco, many pesticides, mercury, chlorine and endocrine-disrupting compounds, as well as chlorofluorocarbons, high sulphur fuels and fossil fuels in general^{82,83}. In all these and many other cases, delayed recognition of adverse effects incurred not only serious environmental or health impacts, but massive expense and reductions in competitiveness for firms and economies persisting in the wrong path^{84 85}. Innovations reinforcing fossil fuel energy strategies⁶⁵ – like hydraulic fracturing⁸⁶ – arguably offer a contemporary prospective example. And similar dilemmas are presented by the otherwise exciting new possibilities of nanotechnology⁸⁷ – both internally within this field and externally with respect to alternative ways to address the same priority social needs⁸⁸.

The key conundrum here, is that each alternative innovation pathway in any given area (like food, energy, health or security), will typically display contrasting pros and cons under contending perspectives. Animated differences emerge, for instance, around infrastructures for urban automobiles or cycling⁸⁹, nuclear power or renewable energy⁶⁶ and violent or peaceful approaches to national security^{50 49}. Each involves different innovation trajectories. Competing pathways will also routinely differ in their social distributions of benefits and harms, winners and losers. And – in any view – the whole picture is further obscured by many deep unknowns. Crucially, a decision *not* to innovate will also present its own mix of pros, cons and uncertainties. Innovating in any particular direction will – for instance, through foregone resources and opportunity costs – typically diminish innovation in others. Whether deliberate or inadvertent, each direction for

innovation is a social choice – involving issues of uncertainty, legitimacy and accountability as well as competitiveness.

It is important to acknowledge these complexities of choice, because innovation debates in particular areas often become quite simplistic and polarised. For instance, innovation in fields like food, health, energy or warfare is frequently discussed as if it were a one-track race⁷⁰, rather than an exploratory process – simply about whether to ‘*go forward*’ or not. But the crucial questions in such areas are typically not just about ‘*yes or no?*’, ‘*how fast?*’ or ‘*who’s winning?*’. What often matters more instead, are queries over ‘*which way?*’, ‘*what alternatives?*’, ‘*who says?*’ and ‘*why?*’⁹⁰. And the scope for uncertainties under these wider questions, compound the scope for controversy. So, conflicts can become especially intensive and disabling (and potentially economically disastrous), if these broader questions are ignored.

Across all fields, the key challenge is that there exists no single definitive ‘sound scientific’ or ‘evidence based’ way to calculate the most rational balance of resources to expend on alternative innovation pathways within or across different domains⁹¹. A robust knowledge base and rigorous analysis are both necessary. But these are typically insufficient. The merit rankings constructed for different innovation choices by expert analysis invariably overlap – and may often be inverted – under contrasting equally reasonable assumptions and value judgements^{92 93 94 95 96}. Decisions concerning which kinds (or areas or aims) of innovation to prioritise are therefore inherently partly subjective, rather than purely technical or economic. This is why research and innovation remain intrinsically political matters, irrespective of whether or not they are acknowledged to be so.

This makes it all the more important that high quality information concerning public policy in and around innovation, is available for wider scrutiny and debate. But the recent House of Lords Select Committee on Science and Technology report on the setting of priorities for publicly funded research, identified several important areas for improvement⁹⁷. The Committee confirmed that there remains important scope for enhancing the quality of official UK statistics concerning public support for contrasting innovation pathways. It made recommendations that this information be clarified in several particular ways. Yet these recommendations remain to be implemented. Consequently, further deliberate efforts are required in order to enable more transparent and accountable democratic politics concerning the directions and rationales underlying UK innovation policy.

3: Steering Innovation Pathways

One reason why it is important to address the politics of choice in innovation, is that chosen pathways can quickly become effectively irreversible. A diversity of well understood social, political and economic processes exert various kinds of positive feedback as innovation pathways unfold. These can act to reinforce the trajectories favoured by the most powerful interests, and exclude others that may be more widely beneficial.

Typically, it takes a lot of effort for people, organisations and markets to learn about any new way of doing things, capitalise on the opportunities and adapt to the changed requirements. As these efforts become 'sunk investments' in a particular innovation, they can help reinforce commitments to the associated pathway. This can occur, even if the innovation in question is widely seen to be unsatisfactory⁹⁸. Although complicated⁹⁹, a classic example of this remains the QWERTY keyboard^{100,101}. This was originally designed for nineteenth century mechanical typewriters, specifically to adjust typing in order to reduce jamming of the type bars for letters frequently used together. But this very property of modulating typing speed, helps aggravate office injuries¹⁰². There exist better keyboard configurations¹⁰³. Yet the deeply socially embedded familiarity of QWERTY makes it difficult for alternatives to become established. So, the problem persists through successive innovations in electronic typewriters, computers and touchscreen tablets, continuing several technological generations after the initial rationale lapsed. Even where the incumbent innovation is essentially a product of historical chance, then – with no powerful backing – it can prove very difficult to reverse the associated path dependency.

This dynamic of path dependency makes it especially important to do whatever is achievable at the earliest stages of innovation, to give confidence that unfolding directions are as appropriate as possible¹⁰⁴. The dilemma is, of course, that this is precisely the time when the positive and negative implications are most uncertain^{105,106}. So, there can be enormous pressures on all sides, to exaggerate the confidence with which evidence can be interpreted and to understate the scope for competing interpretations¹⁰⁷. One reasonable response to this, is to be much more open and questioning about uncertainties⁹¹. Another rational measure, is to extend scrutiny beyond anticipated consequences and also look at the driving purposes of innovation¹⁰⁸. Whilst the variously claimed positive, negative and indirect effects may remain uncertain, the motivating values, interests and incentives that lie behind particular innovation pathways are typically much clearer¹⁰⁹. In this way, critical appraisal of the driving forces behind alternative innovation pathways (not just the claimed aims) can be undertaken with confidence at an early stage, despite the uncertainties¹¹⁰.

This kind of careful broad-based societal consideration is, however, rarely evident in mainstream innovation. More often, it is a narrower range of expectations about the future that most strongly drive directions for change. The values upheld by particular communities of researchers themselves may be influential, as well the interests of leading firms, powerful financiers or particular users¹¹¹. If a specific pathway is strongly held to be more likely than others by these kinds of influential actors, then this can become self-fulfilling¹¹². Examples include competing media formats or software operating systems, where early market penetration can be driven more strongly by expectations about future adoption, than by assessments of performance⁷³. Some degree of performance shortfall is often the

price for collective compatibility¹¹³. Consequently, expectations can add to path dependencies mentioned above, compounding the 'locking in' of a particular innovation, and the 'crowding out' of alternatives¹¹⁴. This is an issue that arises, for instance, from the conditions described in Box Y in the case of nanotechnology⁵⁸.

Processes of learning, volume production and economies of scale can add to these positive feedbacks. For instance, 'lock in' can be significantly further reinforced by measures to standardise infrastructures¹¹⁵, establish organisational momentum¹¹⁶, appropriate intellectual property^{117 118}, build monopolies¹¹⁹, realise rent on value chains¹²⁰, condition user preferences through marketing¹²¹, 'capture' regulators¹²² and 'entrap' competing political interests¹²³. The overall result of such so-called 'network externalities', are a range of powerful 'increasing returns' that can entrench a particular favoured trajectory and exclude other paths¹²⁴. Despite being ignored in the apparently simple policy language of '*going forward*', these more complex dynamics in science and innovation do not go unnoticed by interests wishing variously to reinforce (or disrupt) particular pathways^{125 126}. So, if innovation policy is to be fair and effective, it is therefore important that it attends to these processes in explicit, direct and accountable ways.

These challenges are formidable enough. But, as indicated above, problems of 'lock in' are intensified where important roles are also played by the deliberate exercise of powerful interests at the earliest stages of an innovation process, in order intentionally to promote particular favoured pathways or disadvantage others^{127 128}. For instance, automobile manufacturers and allied industries sought historically to promote the car by suppressing competing urban public transport systems¹²⁹. Likewise, lead compounds were promoted as anti-knocking agents in transport fuels, at the expense of less profitable alcohol-based products, even though these were very early known to be less harmful⁸². A further example of this more deliberate type of lock-in includes the strategies of the tobacco industry over the past century to maintain high levels of consumption¹³⁰. Before it was finally abandoned in most countries, the nuclear fuel reprocessing industry also worked for many decades actively to engineer continuing government support¹²³. And now, ostensibly disinterested debates over alternative radioactive waste management strategies also inherently depend on – and help condition – future prospects for new nuclear power^{131,132}. Most recently, pharmaceutical industry strategies have been challenged for neglecting innovation of medically vital antimicrobials due to their low profitability¹³³. Where innovation systems are driven by these kinds of dynamics, there are especially important roles for democratically responsive government policy and collaborative international pressure.

It is crucial not to misunderstand the implications of 'lock in'. In order to be successfully achieved, even the most positive innovation pathway will require some closing down in associated standards, regulations and practices¹³⁴. So 'lock in' in some sense, is not in itself necessarily a bad thing. But it remains a significant policy dilemma, since it means that not all potentially good innovations that are technically practicable, economically feasible or socially viable will actually prove to be historically realisable. The most important point then, is that these issues need to be discussed and addressed openly – and democratically – rather than brushed under the carpet or drowned in simplistic and polarising 'pro' claims (or 'anti' accusations) over innovation in general.

4: Opening Up Innovation Portfolios

Many of the above examples are retrospective – judged with the benefit of hindsight. Looking forward in any given area, it becomes even more difficult to conclude definitively which of a variety of innovation pathways offers the most favourable balance of pros and cons. One especially important prospective example lies in the field of innovation for more Sustainable global food systems¹³⁵. How will a growing world population be fed at a time when natural environments are increasingly stressed¹³⁶? Here there exists a particularly rich diversity of possible innovation pathways, each with contrasting implications¹³⁷. Many kinds of diversity are possible¹³⁸. But public debates display a shared tendency on all sides to close down discussions as if about just being ‘for’ or ‘against’ the single family of innovations around ‘genetic modification’ (GM), favoured by the most powerful interests in this sector.

With resulting policy debates polarised by this especially deep form of power play^{139 140}, it is often portrayed as if GM were – self-evidently and in-principle – either individually indispensable or uniquely unacceptable. Whatever reasonable political perspectives are taken on the pros and cons of the many disparate innovation pathways in this field, neither of these positions is actually tenable. In fact, the much-discussed (apparently specific) innovation of ‘GM plant breeding’ is much more complex and ambiguous than often suggested by either critics or advocates alike. Apparently technical variations like ‘transgenics’, ‘cisgenics’, ‘apomixis’, ‘gene editing’, ‘genomic assist’ and ‘marker selection’¹⁴¹ each offer partly overlapping and partly contrasting benefits and risks – and present important differences in their potential social, political, economic and ecological implications¹⁴².

For example, among the more striking recent claims made for UK Government supported research towards enhanced Sustainability in global staple crops, are the remarkable flood tolerance qualities reported for ‘scuba rice’¹⁴³. But these have been achieved through ‘marker assisted backcrossing’, rather than any form of transgenics¹⁴⁴. So, the most important factor typically differentiating “GM” technologies is not that they offer a unique means to secure crop improvement. The crucial distinction lies more often in the potential for innovating firms to recoup investments by obtaining rents on intellectual property or global supply and value chains¹⁴⁵. For instance, transgenic crops are often deliberately engineered for tolerance to particular proprietary broad spectrum herbicides, thus expanding their sales¹⁴⁶. Or the inclusion of particular transgenes can make the resulting organisms patentable, and thus more reliable sources of royalties¹⁴⁷. It is the resulting forces and counterforces that help make the ensuing discussions so regrettably polarised.

This point becomes even more important as attention extends beyond science-intensive innovations. Outside the techniques of molecular genetics, there are many other promising innovations for improving global food sustainability¹³⁷. These include participatory breeding¹⁴⁸, agricultural extension services¹⁴⁹ and open source seed sharing methods¹⁵⁰, which harness the innovative capacities of farmers themselves and help tailor crop development to important local conditions¹⁵¹. Likewise, there exist many innovations in wider agricultural practices that also offer significant benefits to the productivity of small

farmers¹⁵², including intercropping¹⁵³, integrated pest management¹⁵⁴ and other methods of ecological farming¹⁵⁵ and Sustainable agriculture¹⁵⁶.

Likewise organisational innovations in the food chain also offer potentially major benefits, including reforms to distribution systems, storage provision and better food waste management¹⁵⁷. Arguably the greatest implications for equitable global food availability, however, are presented by innovations that are still wider in scope¹⁵⁸, including reforms to land tenure and agricultural property rights¹⁴⁸, income support for marginal farmers¹⁵⁹, social equality between different rural groups¹⁶⁰, or moving diets towards lower meat consumption¹³⁷. These kinds of innovation may often offer significantly greater benefits to poor farmers, consumers or communities than science-intensive technological solutions. But their less attractive commercial benefits mean they remain, like Cinderella, too often uninvited to the innovation party.

What is shown by this food sector example, is that – even in a specific area – innovation is not about simply *‘forging ahead’*, *‘lagging behind’* or *‘catching up’*¹⁶¹. It is not a single-track race driven by a particular privileged field of science. Instead, it is about diversity, exploration and choice. This is why it is misleading to uphold particular pathways as offering exclusively *‘sound scientific’*, definitively *‘evidence based’* or uniquely *‘pro innovation’* options (...or for all contingently-emerging innovation to be asserted necessarily to be “great”). And this is why exaggerated *‘no alternatives’* language (on any side) can polarise controversy and so also impede effective innovation policy. By seeking to invoke the general authority of science and technology in partisan ways, this kind of language does not only threaten effective innovation. It also risks compromising science and undermining democracy itself¹⁶². More mature and rational debate recognises that choosing between the pros and cons of alternative innovation pathways like those exemplified here, are less technical than they are political.

A more reasonable and productive way to handle these crucial issues in innovation policy is to be more transparent, deliberate and accountable about when it is right to ‘open up’ and when to ‘close down’ in any particular field¹⁶³. This means that no particular innovation should be unduly favoured by policy making, simply because of its appeal to particular powerful vested interests within a given innovation system. Nor should it be treated on these grounds as self-evidently existentially unacceptable. Either position requires context and perspective -specific argument. In other words, what is needed is mature political debate, as much as ostensibly definitive analysis¹⁶⁴. What can be recognised as well, though, are the benefits of some requisite degree of diversity¹⁶⁵. And (as we shall see), this is a general quality that can be achieved in many different ways – also potentially excluding any particular innovation.

This can be illustrated by the further example of the challenge of mitigating climate change by building zero carbon energy infrastructures. Here decades of intensive research by government and industry bodies has shown that there exist (despite the formidable constraints) a range of alternative innovation pathways that are viable under contrasting equally-informed understandings¹⁶⁶. For some, the solutions centre around nuclear power¹⁶⁷. Others highlight large scale use of carbon capture and storage¹⁶⁸. In the wings, momentum is growing behind expedient and idealised aspirations somehow deliberately to

control the global climate through ‘geoengineering’^{169–173} – a technology threatening particularly acute and irreversible forms of ‘lock in’^{174 175}. Yet all the time (albeit not backed by such powerful interests), a rich array of renewable energy technologies is available for addressing climate change in a diversity of radically different distributed or centralised ways^{176–179}.

The crucial point is, that there is no definitive technical or economic reason why any of the above energy strategies cannot (for better or worse) provide a basis for a variety of zero carbon UK or global energy futures. Crucially, this includes the clear feasibility (equally for the UK and Europe^{180 181 182 179 183 184} and the world as a whole^{166 185 118 119}) of energy strategies built entirely around efficiency and renewables. Yet one of the main obstacles to this, lies in high profile self-fulfilling assertions to the contrary – including by authoritative policy figures^{188 189}. In energy as in the food sector discussed above, then, the obstacles to less favoured strategies are typically more commercial, institutional and cultural than they are technical. Amongst the most potent of these political obstructions are claims from partisan interests – like incumbent nuclear or fossil fuel industries – that there exists ‘no alternative’ to their favoured innovations and policies¹⁸⁸. Even given the formidable constraints bearing on sustainable energy and agriculture then¹⁹⁰, there remains much hidden scope for radical choice. This is a matter for critical democratic deliberation as much as technical analysis³⁹.

There are many ways to resist such unhelpful syndromes and to develop more reasonable debates about innovation. These will be returned to below. Some are about the style of discourse – developing a greater tolerance on all sides, for embracing adverse public reactions to particular innovations. When they transcend privileged ‘not in my backyard’ parochialisms, general public preferences offer an important guide to the general orienting of innovation¹⁹¹. Just as scepticism is one of the crucial constituting qualities in science itself^{192 193}, so space for healthy critical debate and public dissent can help improve the quality of innovation more generally^{194 195}. With mainstream institutions often especially strongly disciplined by incumbent powerful interests, the role of delivering on this important quality of scepticism often falls disproportionately to civil society¹⁹⁶.

And this crucial role of social movements and wider civil society extends beyond debate and controversy. It is remarkable how many presently major global industries are building around once-marginal technologies like wind turbines, ecological farming, super energy-efficient buildings, or green chemistry⁷. All of these owe key elements in their pioneering origins to early development by grassroots social movements¹⁹⁷. For instance, without the small country of Denmark remaining partly ‘below the radar’ of international nuclear interests, able to nurture alternative energy strategies in the 1970s driven strongly by anti-nuclear social movements, it is arguable that the present multinational wind industry might never have become competitive¹⁹⁸. This is just one of the examples of innovations that were systematically marginalised – sometimes actively suppressed – by incumbent interests in science, government and industry¹⁹⁹.

It is of course important not to become too romantic about the dynamics of social movements and their favoured innovations¹⁹⁶. These too warrant exactly the same kinds of healthy scepticism appropriate to other actors in innovation debates. But history does

make clear where it is that many of the ostensibly driving environmental and social justice concerns come from, that currently play such prominent roles in the justification of innovation policy. Without decades of struggle by social movements dedicated to humanitarianism, environmentalism and social justice, it is doubtful that high level global agenda-setting developments like the Stockholm Environment Conference or the Brundtland Commission or the Millenium Development Goals would ever have become as formative as they are now in shaping the general climate of global governance – or innovation debates in particular^{200–203 204,205 206}. Here, the same basic pattern is arguably reproduced, as in the crucial roles played by social movements in other emancipatory transformations around colonialism, slavery, women’s and gay rights^{207 208 209,210}.

Just as the famous astronomical missing mass stabilises the visible structures of galaxies, so these apparently intangible distributed social forces help condition the gradients that ultimately help forge and steer new directions for innovation²¹¹. The greater the critical interest in the most progressive orientations for innovation – rather than those that preserve the status quo – the more this is generally true.

5: Risk, Uncertainty, Ambiguity and Ignorance

As has been mentioned, these policy making challenges are compounded, because the pros and cons of different innovation pathways are – under all views – subject to seriously incomplete knowledge. The normal way to address these dilemmas, is by means of regulatory risk assessment^{212 213 214}. Although often not implemented in full, this prevailing approach invokes the apparent authority of probabilistic analysis^{215 216 217} to assert a notionally single ‘sound scientific’ or ‘evidence-based’ picture^{218 219 220 221}. This task can be approached in many variously complex ways^{222 223 224}. But at root, it involves alternative possible positive and negative outcomes being weighted by their respective perceived likelihoods to derive a single overall ‘expected value’ for the balance of future benefits and harms^{225 216}.

In conventional innovation policy and regulation then, it is simply assumed that whatever products or technologies are most energetically advanced for assessment of risk, are in some way self-evidently beneficial^{226 227}. Questions then typically focus on whether any associated risks will be ‘tolerable’^{228 229 230}. It is rare for the claimed benefits themselves to be rigorously scrutinised²³¹, let alone compared in a balanced way with other potential benefits of alternative innovation pathways^{232 83}. So, existing forms of risk regulation do little to address the wider issues in innovation politics discussed above.

Further challenges arise in the reliance of risk-based regulation on the methods provided by probability theory^{233 234}. Probabilistic tools can be useful in tackling familiar, high-frequency, relatively unchanging challenges, as found (for instance) in risk regulation of many urban transport or public health systems^{235 236}. Where empirical evidence arising in past experience is held to be a reliable guide to the future, these tools can be very powerful – as in established responses to familiar safety risks²³⁷. But where an innovation pathway (or its context) is novel, complex or rapidly changing, uncertainties cannot confidently be reduced to single definite probabilities²³⁸. Such inability to justify a single picture of probabilities can arise, for instance, in the regulation of nanotechnologies²³⁹ (see Box Y), endocrine disrupting chemicals²⁴⁰, or novel living organisms²⁴¹. Under these conditions, it can be irrational to assert a single definitive ‘evidence based’ picture²⁴². In these fields (as more widely), policy making must often contend with contrasting – but equally reasonable – interpretations of uncertainty^{107 91}. These cannot reliably or rationally be reduced to simple single numbers for probabilities.

These are not the only limits to risk assessment. Beyond uncertainty in the above sense^{243 244 245}, there exists a further array of challenges^{246 247}. These involve not the relative likelihoods of different outcomes, but the meanings of the possibilities themselves. For instance, divergent views may exist over how to categorise or partition different kinds of benefit or harm. Or there may be major questions over how to frame the various dimensions under which these are defined²⁴⁸. What are the appropriate imaginations, understandings, values, or interests according to which they should be interpreted or prioritised²⁴⁹? There may also be differences over which innovation pathways to include or exclude from scrutiny, or how to allocate attention¹⁰⁵.

These are challenges of ambiguity, rather than strict uncertainty²⁵⁰. Here, the problem is not so much about uncertainty, as contradictory certainties²⁵¹. And risk assessment is no more able fully to resolve these disagreements over meanings as over likelihoods²⁵². Indeed, Nobel Prizes have been awarded in rational choice theory, for axiomatic proofs demonstrating there can be no definitive way to guarantee the calculation of a particular optimum balance between contending ways to interpret, measure or prioritise possible outcomes^{253 254 255}. Yet such challenges remain not only the norm in many innovation debates, but constitute the key issues in contention in controversies like those over alternative agricultural, energy or health strategies²⁵⁶. Under ambiguity, claims to single definitive ‘sound scientific’ or ‘evidence-based’ prescriptions are not only seriously misleading, they are an oxymoron²⁵⁷.

The above difficulties may seem tricky enough. But even more intractable than uncertainty and ambiguity, is the further challenge of ignorance^{258 106 246 259}. Here possibilities are not just disagreed about, but at least some are entirely unexpected^{247 260}. This was the case, for instance, in the early regulatory history of bovine spongiform encephalopathy (BSE)²⁶¹, endocrine disrupting chemicals²⁶² and damage by CFCs to stratospheric ozone²⁶³. Like many other cases^{82,83}, these involved mechanisms that were not just thought unlikely at the inception of the issue, but were at the time ‘unknown unknowns’²⁶⁴. Where we don’t know what we don’t know²⁶⁵ the prospect is raised of possible ‘black swans’²⁶⁶. These challenges are not about calculable risk, but inherently unquantifiable surprises^{267,268}. Here again, to seek to assign single definite values for ‘risk’ are not just irrational but dangerous²⁶⁹.

Of course, surprise is not necessarily always a bad thing. It is intrinsic to the rationale for ‘blue skies’ science – as well as research and innovation more generally – that positive benefits can also be entirely unexpected²⁶⁷. An example might be the laser – a novel laboratory phenomenon that was for a long time a ‘tool’ without a use²⁷⁰. Likewise (albeit involving many variously questionable applications), the internet has also undoubtedly given rise to a host of positive benefits that were initially entirely unexpected²⁷¹. But it is also clear – for instance in areas like nanotechnology (Box Y)²⁷² – that there is no guarantee that further research will necessarily reduce uncertainty, ambiguity or ignorance²⁷³. As Einstein famously observed, it is often the case that the more we learn, the more we find we don’t know²⁷⁴. And, of course, this is not necessarily bad. Indeed, it is a key motivation in science²⁷⁵. It is political pressures that resist the humility of acknowledging ignorance²⁷⁶.

Either way, it is clear that some of the greatest dilemmas in innovation governance extend well beyond risk – they are about surprises. With conventional regulatory risk assessment entirely unable to deal with this deepest form of incertitude, the importance of robust critical deliberation and wider political argument about innovation, is seriously reinforced.

6: Precaution and Diversity

One widely established and intensely debated response to these challenges in innovation policy, is the precautionary principle^{277 278 279}. Although it comes in many forms²⁸⁰, a classic general expression of precaution, is that scientific uncertainty is not a reason for inaction in preventing serious damage to human health or the environment²⁸¹. By explicitly hinging on uncertainty rather than risk, precaution helps promote recognition that social choices in innovation are not reducible to ostensibly precise, value-free, technical risk assessments²⁸². These dilemmas are instead explicitly recognised to involve wider issues and alternatives requiring overtly value-based – and so ‘political’ in this sense – deliberations over policy.

This message is inconvenient to many partisan perspectives wishing to dragoon the authority of science as a whole in favour of specific interests²⁸³. Often driven by such motives, opposition to precaution rests largely on assertions (or assumptions) that established ‘science based’ regulatory risk assessment offers a sufficient general response to the challenges of social choices across alternative innovation pathways – and a particular way to justify favoured technologies^{284 285}. So, precaution remains a subject of much misunderstanding and mischief^{286 287 288 289}. This often involves ironically emotive rhetoric in supposed defence of reason²¹⁹. It is on these grounds, for instance, that arguments are sometimes made that it is somehow irrational not to always use probabilities to qualify potential hazards²⁹⁰. In this way, many critics of precaution mistakenly ignore uncertainty, ambiguity and ignorance, insisting instead that these be treated as if they were risk²²⁵. The precautionary principle has played a crucial role in fostering more rational reflection about these highly political pressures on the use and abuse of science in technology regulation.

Treating general dilemmas of uncertainty, ambiguity and ignorance as a simple state of risk, perpetrates the misunderstandings discussed above – that probabilistic analysis is universally applicable and that innovation is a single-track race. When these misapprehensions are corrected, precaution can be recognised simply as a guide to the more reasonable and realistic steering of social choice among possible innovation pathways²⁹¹. So precaution is not (as often alleged) about being somehow generally ‘anti-innovation’ or ‘anti-science’^{292 293 219}. Instead, it simply urges greater rational consideration of different aspects of uncertainty than can reasonably be reduced merely to risk^{83,264,269,294,295}.

Consequently, precaution does not automatically mean abandoning any particular innovation, still less innovation in general²⁹⁶. Contrary to many claims²⁹⁷, there is nothing inherent in the precautionary principle that automatically requires bans²⁹⁸, or makes it partisan in its applicability to innovations of contrasting provenance^{299 300}. Precautionary action inhibiting any one innovation pathway, inevitably favours another²⁹⁴. And precaution does not even mean abandoning risk assessment^{237,301}. It simply reminds that risk-based approaches do not offer a complete response to deeper challenges of choice.

Precaution is also a guard against the error of treating absence of evidence of harm as evidence of absence of harm³⁰². This is often a particular danger for innovations whose novelty means there has been little time for evidence to accumulate, or where incumbent interests discourage research or assessment of the requisite kinds³⁰³. Before invoking a

lack of evidence of harm, it is necessary to think about how visible this evidence might actually be expected to be if it existed – or how vigorously it is sought³⁰⁴. Identifying false negatives is often more important than avoiding false positives⁸². In this respect, precaution is a guard against wilful and misleading blinkers favouring incumbent interests and the inertia of the status quo³⁰⁵.

In essence, precaution simply highlights that innovation policy and associated politics should pay more careful attention to the intrinsically problematic nature of knowledge – and its vulnerability to economic and political pressures. But it does not just highlight problems. The precautionary principle also opens the door to solutions – pointing to a range of rigorous and practical strategies and practices for dealing with the realities of uncertainty, ambiguity and ignorance in innovation^{83 269 282 306 307 308 309 310 311}. These ‘Cinderella methods’ can be neglected, where there persist preoccupations solely with deterministic notions of ‘risk’, ‘exposure’ and ‘vulnerability’ (rather than ‘uncertainty’, ‘ambiguity’ and ‘ignorance’) – and a consequent sense that risk assessment alone is sufficient²⁶⁹. Practical examples include a range of different tools for ‘opening up’ regulatory appraisal³¹², research strategies³¹³ and innovation policy³¹⁴, as well as more general prioritising of qualities like reversibility³¹⁵, resilience³¹⁶ and flexibility³¹⁷.

Rather than resting hubristically on an ostensibly definitive picture in the balancing of benefits and harms, these precautionary strategies acknowledge stronger grounds for greater humility²⁷⁶. Instead of wishful thinking about the quality of risk information, they prioritise more humble measures to consider alternatives, explore uncertainties, maximise learning²⁴⁶ and promote adaptability³¹⁸ in careful, reversible, step-by-step implementation³¹⁹. Where there is uncertainty over probabilities, potential hazards do remain relevant in their own right – with particular care necessary where they might be irreversible²⁹⁸. And the dilemmas are accentuated where associated infrastructures might also prove to be especially inflexible²⁹⁹. All else being equal, where a range of innovation pathways look as if they present similar balances of pros and cons, precaution simply highlights that it is reasonable to prioritise that which is more reversible over the less flexible alternatives³²⁰.

At root, a key value of precaution lies in helping to free policy debates from the Panglossian fallacy that the most powerfully favoured innovation pathways are somehow necessarily the best or only option³²¹. It reminds that particular values (other than profit), also need to be prioritised – especially around human health and environmental integrity³²². This enables societies to discuss rationally and directly when it is right for governance deliberately to discourage or discontinue a particular entrenched trajectory³²³. The crucial point is, that precaution makes this possible without incurring existential anxieties over innovation in general. As a general principle, it offers a practical and flexible means to avoid simply relying on optimistic hopes that powerful vested interests will automatically be spontaneously relinquished or themselves become entirely benign.

And in this, precaution points to a further quality in research and innovation systems, namely diversity. Even though it is not a panacea, nor a ‘free lunch’³²⁴, nor self-evident in its composition, diversity is a vital consideration in research and innovation policy⁷⁷. Like other strategies, it brings its own challenges and remains intrinsically a matter for political judgement. But in any given area, recognition of the importance of diversity encourages

caution about concentrating resources in support of the particular innovations that happen to be favoured by the most powerful interests³²⁵. Diversity urges instead greater attention to alternatives, leading to more deliberately and systematically-constituted portfolios comprised of some balanced variety of disparate innovation pathways⁷⁷.

In these terms, diversity offers a remarkably practical way to help address several otherwise intractable innovation problems. It offers a 'resource pool'³²⁶ helping to nurture creativity⁶⁸, mitigate lock-in¹²⁴, hedge against surprise³²⁷, accommodate ambiguity³²⁸, resolve irreconcilable interests³²⁹, promote learning²⁴⁶ and cultivate resilience³³⁰. And by fostering more intensive encounters between varying kinds of knowledge and practice, deliberate diversification can also help enhance innovation processes themselves³³¹ – and make them more effective and socially robust³³². It is remarkable to find so many otherwise intractable challenges addressed (albeit always provisionally and incompletely) by a single operational strategy. And there exist plenty of useful tools to help focus more concretely at the level of diverse innovation portfolios, rather than individual programmes^{333 334 335}.

Consequently, deliberate diversification is one key pragmatic way to enable greater precaution, while also helping to diffuse unhelpful polarisation in debates over innovation³³⁶. This is aided by more explicit and measured pursuit of repertoires of innovations in particular areas, rather than single privileged supposedly 'sound scientific', 'evidence based', 'solutions'. Moreover, a focus on diversity may also help develop greater political tolerance, for the otherwise difficult – but inevitable – kinds of failure that are so essential to effective learning³³⁷. If commitments lie at the level of diverse portfolios rather than single supposedly 'no alternative' solutions, then it becomes easier to accept and justify the kinds of failures that contribute so much to learning.

To help realise these concrete benefits, however, diversity must move away from being a fig leaf or argument-of-last-resort for some otherwise ill-favoured but powerfully-backed choice³³⁸. It is all too easy to support otherwise indefensible proposals, simply on the grounds that "we must do everything"³³⁹. This invites powerful interests to insist on adoption of their own preferred policy, simply on grounds that every option must be pursued³⁴⁰. There are typically many kinds of diversity, each exclusive in some ways and inclusive in others^{325 341}. So, as with individual innovation pathways, the detailed constituting of diversity also involves inherently political judgements. By urging this greater attention to diversity (as in other ways), precaution can be as much a spur to innovation in general, as a brake on any specific kind.

7: Three Key Conclusions

Formulating an adequate response to the challenges discussed in this paper requires being clear about the resulting practical implications for policy. Here, there have been many recent interventions developing concrete recommendations for research and innovation practices and the wider policy procedures and political debates in which these are set. The European Science Foundation reviewed key background in research and innovation systems across Europe³⁴². The Expert Group on Science and Governance put this in the context of the European ‘Knowledge Society’²⁹⁵. The Nuffield Council on Bioethics recommended new institutional ways more effectively to govern emerging technologies⁵⁸. The EPSRC identified a number of responsibilities to be encouraged across all actors in innovation systems³⁴³. An ESRC-funded ‘new manifesto’ explores some of the global implications³⁴⁴. And many other international initiatives contribute much further detail^{345 346,347}. But the general practical upshot is quite readily summarised in terms of three overarching principles: **participation, responsibility and precaution**³⁰⁵.

First, there is **public participation in innovation**. Here, innovation strategies should more explicitly and transparently acknowledge the inherently partly political (rather than restrictively technical) nature of the interests and motivations driving contending pathways. This requires many forms of sincere, well-resourced, participatory deliberation – especially including the most marginalised interests³⁴⁸. This is not about fostering credibility, trust or acceptance, but about informing policy and helping substantively to determine the priority directions for research and innovation themselves³⁴⁹. Nor is participation about ‘political correctness’ or relativism about science (implying a position that ‘anything goes’³⁵⁰). Indeed, it offers the most effective way to draw on wider knowledges in order to illuminate how dominant narrow understandings are often untenable. In essence, public participation in innovation is simply about more rigorous exploration of specific ways in which legitimate judgements about ‘benefits’, ‘excellence’, ‘relevance’, ‘risk’, ‘evidence’ and ‘impact’ all depend in part (but irreducibly), on contexts, values and assumptions.

In other words, public participation addresses the fact that what counts as a positive direction for research and innovation in any given area is inherently ‘plural and conditional’¹³⁴. ‘Plural’, because a number of contrasting pathways are typically equally valid³⁵¹. ‘Conditional’, because this validity depends partly on perspectives and circumstances. A rich variety of carefully-developed inclusive, participatory and deliberative practices are available to address this challenge, with varying kinds of value in different circumstances^{352 353 354 355 356 357 358 359}. And crucially, participation does not just mean talking about innovation, but also inclusion in the means for supporting the actual doing of innovation itself^{7 84 199 345 360 361}. Here, there are key roles for the creative arts, humanities and local communities as well as workers and civil society more generally. Some approaches are more formally structured than others – involving ‘uninvited’ as well as ‘invited’ participation³⁶². Together, these help ‘open up’ deeper and wider explorations of practical alternatives³¹⁴. In this way, diverse styles of public participation supplement, enrich and inform (rather than substitute), the conventional procedures of representative democracy³⁶³. And freed from pressures to pretend at (potentially enormously expensive and protracted) ostensibly singular definitive ‘evidence based’ status, unfolding processes of

innovation can become not only more democratically accountable and legitimate, but also more efficient and timely.

Alongside (and mutually reinforcing) greater participation, there is a second major policy imperative. This is for **all actors involved in research and innovation processes** – especially the most powerful – to assume more direct and explicit **responsibility** for the consequences and uncertainties of their activities. This in turn requires serious efforts on the part of innovators to be reflective in anticipating, analysing and addressing the impacts that might arise, as well as their attendant ambiguities and unknowns. It helps avoid the “organised irresponsibility” of otherwise ‘passing the buck’ to insurers, regulators, victims, the state, or ‘society’ at large to deal with inevitable unintended and indirect outcomes ³⁶⁴. And (assisted by participation) responsibility involves being more openly accountable for motivating aims and interests. So, responsibility is not about aspiring – let alone claiming – to predict or control consequences ³⁶⁵. Nor is it about simple exhortations to trust ³⁶⁶. Instead, responsibility is about trustworthiness ³⁶⁷. It means going beyond conventional narrow institutional and economic interests, to care – and be accountable – for wider social and environmental concerns and implications.

A crucial aim of responsibility is that scientists, engineers, businesses, regulators – and government itself – move away from fixations merely with ‘risk’ around whatever are the particular privileged pathways for innovation in given fields. Instead, responsibility on the part of these influential actors, helps inform and open the necessary space for participation by others: by illuminating contending motives and a range of alternative directions for progress. Nor is there anything about this, that necessarily impedes decision making on innovation – or makes it more protracted or burdensome. Indeed, by helping to avert ill-advised trajectories at an early stage, participation and responsibility can assist innovation to become more effective in addressing diverse social values of a kind that might otherwise invite a costly backlash ⁶². But there do arise here, particular responsibilities for the media. The discussion in this paper has shown that it is quite simply irresponsible to pretend (as is too often the case ³⁶⁸) that science and technology are free of interests, values or alternatives ^{369 370}. What is required instead, is less simplistic and romantic portrayals of technical expertise ³⁷¹. The media hold especially important responsibilities for enabling more realistic, mature and open debates about the inherently contestable and power-laden nature of both scientific knowledge and technological innovation ³⁷².

This leads to the third and final general policy implication. This is, that greater and more deliberate efforts are needed to moderate the powerful forces of closure and lock-in in science and technology. It is here that this paper has shown the particular value of **precaution in regulation**. Rather than treating existing patterns of research and innovation as value-free, the precautionary principle strikes an explicitly stronger balance in favour of human health, environmental integrity and social well-being in the steering of priority directions. Thus guided (but not determined) by precaution, participation and responsibility can explore and elucidate more clearly what might be meant by these values in any given context. So together, these complementary principles and practices help provide a selection and balancing process, to harness incumbent and energetic private interests. In particular, precaution directly addresses the tendencies for uncertainties, ambiguities and ignorance to be closed down in the most convenient directions, as if they were just ‘risk’.

When innovation is recognised as a branching rather than single-track process, it becomes clear that precaution is also not about impeding innovation, but steering it in ways that better favour human health and the environment. Acknowledging the scope for systematic deliberation over values, priorities and alternatives under uncertainty, precaution broadens out risk regulation to allow greater space for responsibility and participation – and greater consideration for a wider plurality of issues, options, perspectives and scenarios. This can help enable entrepreneurs, small business, new entrants, civil society groups and marginalised communities (as well as government) to better challenge established trajectories. As we have seen, precaution also implies a greater focus on qualities of diversity, flexibility and responsiveness in technology strategies. And a final key lesson of precaution is that regulation and innovation policy should seek to respect and embrace (rather than manage or curtail) public mobilisation and critical dissent. In essence, precaution expresses the fundamental principle that – in innovation just as in science itself – reasoned scepticism fosters greater quality.

In concluding this paper, then, we can return to a point made at the beginning. In any given area, innovation is not so much about a race to optimise a single pathway, as a collaborative process for exploring diverse alternatives. Current noisy anxieties over ‘falling behind’ in single-track ‘zero sum’ competitive innovation ‘races’ are misleading and counterproductive. They can conceal underlying motives, interests and alternatives – and suppress the associated politics. Instead, inter-related practices of **responsibility** among researchers and innovators, **precaution** in regulatory processes and **participation** in policy making and innovation itself, can help innovation escape from these restrictive fear-driven technical imperatives. They illuminate instead how innovation is fundamentally about the politics of contending hopes ³⁹. Most importantly of all, it is in these ways that narrow technocratic ideas of a knowledge economy ²⁹⁵, can give way to the nurturing of a more inclusive, rational and vibrant **innovation democracy**.

Bibliography

1. BIS. *Innovation and Research: Strategy for Growth - BIS Economics Paper No. 15*. London; 2011.
2. OECD. *The OECD Innovation Strategy: getting a head start on tomorrow*. Paris: OECD; 2010.
3. Foresight_Horizon_Scanning_Centre. *Technology and Innovation Futures : UK Growth Opportunities for the 2020s*. London; 2012.
4. NESTA. *The Innovation Gap: Why policy needs to reflect the reality of innovation in the UK*. London; 2006.
5. Murray R, Caulier-grice J, Mulgan G. *Social Venturing*. London; 2009.
6. TSB. *Concept to Commercialisation: A strategy for business innovation, 2011-2015*. London; 2011.
7. Smith A, Fressoli M, Thomas H. Grassroots innovation movements: challenges and contributions. *J Clean Prod*. 2013;1–11. doi:10.1016/j.jclepro.2012.12.025.
8. Bound K, Thornton I. *Our Frugal Future: lessons from India's Innovation System*. London; 2012:1–94.
9. ERAB. *The new Renaissance: will it happen? Innovating Europe out of the crisis - Third and final report of the European Research Area Board 2012*. Brussels: European Research Area Board; 2012.
10. Malhotra A, Schulte J, Patel P, Petesch P. *Innovation: for Women's Empowerment and Gender Equality*. Washington DC; 2009.
11. CEC. *Reaping the benefits of globalization: European Competitiveness Report 2012*. Brussels; 2012.
12. Harris M, Albury D. *The Innovation Imperative: why radical innovation is needed to reinvent public services for the recession and beyond*. London; 2009.
13. Rejali D. *Torture and Democracy*. Princeton: Princeton University Press; 2007.
14. Piketty T. *Capital in the Twenty First Century*. Cambridge, Mass.; London: Belknap Press of Harvard University Press; 2014.
15. Peoples C. *Justifying Ballistic Missile Defence: technology, security and culture*. Cambridge: Cambridge University Press; 2009.
16. Cimbala SJ. *Nuclear Weapons and Strategy: US nuclear policy for the twenty-first century*. London: Routledge; 2005.
17. Cirincione J. *Bomb scare: the history and future of nuclear weapons*. New York: Columbia Univer Press; 2007.
18. McLeish C, Nightingale P. Biosecurity, bioterrorism and the governance of science: The increasing convergence of science and security policy. *Res Policy*. 2007;36(10):1635–1654. doi:10.1016/j.respol.2007.10.003.
19. Rogers P. *Losing Control: global security in hte 21st century*. London: Pluto Press; 2001.
20. Yanarella EJ. *The Missile Defence Controversy: technology in search of a mission*. Lexington: University Press of Kentucky; 2002.
21. Tenner E. *Why Things Bite Back: technology and the revenge of unintended consequences*. New York: Vintage; 1999.
22. BIS. Innovation is Great... Britain. Available at: http://i.telegraph.co.uk/multimedia/archive/02004/great-innovation_2004849i.jpg.
23. European_Commission. *Reinvent Europe Through Innovation: from a knowledge society to an innovation society*. Brussels; 2009.
24. CEC. *Working Document on the contributions of the future regional policy to the innovative capacity of the European Union Committee on Regional Development*. Brussels; 2006:1–5.

25. Eurobarometer. *Population Innovation Readiness*. Brussels; 2005.
26. Sclove RE. *Democracy and Technology*. New York: Guildford Press; 1995.
27. Winner L, ed. *Democracy in a Technological Society*. Dordrecht: Springer; 1992.
28. Jasanoff S. The Dilemma of Environmental Democracy. *Issues Sci Technol*. 1996;Fall 1996:63–70.
29. Abraham J, Sheppard J. Democracy, Technocracy, and the Secret State of Medicines Control: Expert and Nonexpert Perspectives. *Sci Technol Human Values*. 1997;22(2):139–167. doi:10.1177/016224399702200201.
30. Borgmann A. Technology and Democracy. In: *Technology and Politics*. Durham; London: Duke University Press; 1988.
31. Shrader-Frechette K. "Technology, Bayesian Policymaking, and Democratic Process." *Philos Technol*. 1992;9:123–137.
32. Hippel E von. *Democratizing Innovation*. Cambridge Mass.: MIT Press; 2005.
33. Malerba F, Brusoni S, eds. *Perspectives on Innovation*. Cambridge: Cambridge Univ Press; 2007.
34. CEC. *Gearing European Research towards Sustainability: RD4SD Exercise*. Brussels; 2009.
35. Lightman A, Sarewitz D, Desser C, eds. *Living with the Genie: essays on technology and the quest for human mastery*. Washington DC: Island Press; 2003.
36. Steward F. *Breaking the boundaries: transformative innovation for the global good*. London; 2008:12–3.
37. Scrase I, Stirling A, Geels F, Smith A, Zwanenberg P Van. *Transformative Innovation*. London; 2009:1–67.
38. WBCSD. *Vision 2050*. Geneva; 2010.
39. Stirling A. *Emancipating Transformations: from controlling "the transition" to culturing to culturing plural radical progress*. Brighton; 2014.
40. OECD. *Dynamising National Innovation Systems*. Paris: OECD Publishing; 2002. doi:10.1787/9789264194465-en.
41. OECD. *Governance of Innovation Systems - Volume 1: Synthesis Report*. Paris; 2005.
42. *Who Owns Science? The Manchester Manifesto*. Manchester; 2010.
43. Wyatt S, Henwood F, Lecturer S, Miller N, Senker P, eds. *Technology and In/equality: questioning the information society*. London ; New York: Routledge; 2000.
44. STEPS. *Innovation, Sustainability, Development: a new manifesto*. Brighton; 2010.
45. IRGC. *Risk governance: towards an integrative approach*. Geneva; 2006. doi:10.1515/9783110285161.219.
46. OECD. *Main Science and Technology Indicators: Volume 2013/1.*; 2013:1–30.
47. Alic JA. *Trillions for Military Technology: how the Pentagon innovates and why it costs so much*. New York: Palgrave MacMillan; 2007.
48. Parkinson S, Pace B, Webber P. *Offensive Insecurity: The role of science and technology in UK security strategies*. London: Scientists for Global Responsibility; 2013.
49. North P. *A Human Security Doctrine for Europe: the Barcelona report of the study group on Europe's security capabilities - Presented to EU High Representative for Common Foreign and Security Policy Javier Solana*. Barcelona; 2004.
50. Kaldor M. *Human Security: Reflections on Globalization and Intervention*. Cambridge: Polity Press; 2007.
51. Alic J. *Energy Innovation From the Bottom Up*. Washington, DC; Boston, MA; 2009.

52. Popp D, Newell RG. *Where Does Energy R&D Come From? Examining Crowding Out from Environmental friendly R&D*. Cambridge Mass; 2009.
53. Unruh GC. Understanding carbon lock-in. *Energy Policy*. 2000;28(March).
54. Unruh GC. Escaping carbon lock-in. *Energy Policy*. 2002;30(4):317–325. doi:10.1016/S0301-4215(01)00098-2.
55. WHO. *The 10 / 90 Report on Health Research*. Geneva: World Health Organisation; 2002.
56. Miller P, Wilsdon J, eds. *Better Humans: the politics of human enhancement and life extension*. London: Demos
57. Lilley S. *Transhumanism and Society: the social debate over human enhancement*. Dordrecht: Springer Netherlands; 2013. doi:10.1007/978-94-007-4981-8.
58. Nuffield_Council. *Emerging biotechnologies: technology, choice and the public good.*; 2012.
59. *Neuroscience, society and policy*. London: The Royal Society; 2011:viii, 64 p.
60. Hall B, Rosenberg N, eds. *Economics of Innovation - Volume I.*; 2010.
61. Mazzucato M. *The Entrepreneurial State: debunking public vs private sector myths*. London: Anthem Press; 2013.
62. Owen R, Bessant J, Heintz M, eds. *Responsible Innovation: managing the responsible emergence of science and innovation in society*. Chichester: Wiley; 2013.
63. Jackson T. *Prosperity without growth? The transition to a sustainable economy.*; 2009.
64. Cable V. *Oral statement to Parliament: Innovate 2011*. London; 2011:1–3.
65. Scrase JJ, Smith A, Kern F. *Dynamics and deliberations: comparing heuristics for low carbon innovation policy*. Brighton; 2010:1–42.
66. Scrase I, MacKerron G, eds. *Energy for the Future: A New Agenda*. London: Palgrave Macmillan; 2009.
67. Renn O. *Risk Governance: coping with uncertainty in a complex world*. London: Earthscan; 2008.
68. Page SE. *The Difference: how the power of diversity creates better groups, firms, schools and societies*. Princeton: Princeton University Press; 2007.
69. NESTA. Compendium of Evidence on Innovation Policy. 2011. Available at: <http://www.innovation-policy.net/compendium/>.
70. Broers A. *The Triumph of Technology*. Cambridge: Cambridge Univ. Press; 2005.
71. Dosi G. *Innovation, Organization and Economic Dynamics - Selected Essays*. Cheltenham: Edward Elgar; 2000.
72. Nelson R, Winter S. *An Evolutionary Theory of Economics Change*. Cambridge MASS: Harvard University Press; 1982.
73. Arthur WB. *The Nature of Technology: What It Is and How It Evolves*. London: Penguin; 2009.
74. Frenken K. The early development of the steam engine: an evolutionary interpretation using complexity theory. *Ind Corp Chang*. 2004;13(2):419–450. doi:10.1093/icc/dth017.
75. Saviotti PP, Frenken K. Export variety and the economic performance of countries. *J Evol Econ*. 2008;18(2):201–218. doi:10.1007/s00191-007-0081-5.
76. Frenken K, Saviotti PP, Trommetter M. Variety and niche creation in aircraft, helicopters, motorcycles and microcomputers. *Res Policy*. 1999;28(5):469–488.
77. Stirling A. A general framework for analysing diversity in science, technology and society. *J R Soc Interface*. 2007;4(15):707–19. doi:10.1098/rsif.2007.0213.

78. Rescher N. *Pluralism: against the demand for consensus*. Oxford: Clarendon Press; 1993.
79. O'Neill J. "Pluralism, Incommensurability, Judgement." 1993.
80. Bohmann J. *"Public Deliberation: pluralism, complexity and democracy."* Cambridge MASS: MIT Press; 1996.
81. Stirling A. From Enlightenment to Enablement: Opening up Choices for Innovation. In: Lopez-Claros A, ed. *The Innovation for Development Report*. Basingstoke: Palgrave Macmillan; 2010:199–210.
82. EEA. *Late lessons from early warnings: science, precaution, innovation*. Copenhagen; 2013.
83. Harremoës P, Gee D, MacGarvin M, et al., eds. *Late lessons from early warnings: the precautionary principle 1896-2000*. Copenhagen: European Environment Agency; 2000:1–211.
84. Porter ME, Linde C Van Der. Green and Competitive: Ending the Stalemate. *Harv Bus Rev*. 1995;September-.
85. Wagner M. *The Porter Hypothesis Revisited: A Literature Review of Theoretical Models and Empirical Tests*. Lueneberg; 2003:1–50.
86. RS, RAEng. *Shale gas extraction in the UK: a review of hydraulic fracturing*. London; 2012.
87. Royal_Society. *Nanoscience and nanotechnologies: opportunities and uncertainties*. London; 2004.
88. Kearnes M, Rip A. The Emerging Governance Landscape of Nanotechnology. In: Gammel S, Lösch A, Nordmann A, eds. *Akademisch*. Berlin; 2009:1–35.
89. Schiller PL, Bruun EC, Kenworthy JR. *An Introduction to Sustainable Transportation: policy, planning and implementation*. London: Earthscan; 2010.
90. Stirling A. Pluralising progress: From integrative transitions to transformative diversity. *Environ Innov Soc Transitions*. 2011;1(1):82–88. doi:10.1016/j.eist.2011.03.005.
91. Stirling A. Keep it complex. *Nature*. 2010;468:1029–1031.
92. Stirling A. Limits to the Value of External Costs. *Energy Policy*. 1997;25(5):517–540.
93. Sundqvist T, Stirling A, Soderholm P. *Electric power generation: valuation of environmental costs*. Luleå University of Technology; 2004.
94. Stirling A, Mayer S. A novel approach to the appraisal of technological risk: a multicriteria mapping study of a genetically modified crop. *Environ Plan C-Government Policy*. 2001;19(4):529–555. doi:10.1068/c8s.
95. Saltelli A, Tarantola S, Campolongo F, Ratto M. *Sensitivity Analysis in Practice: a guide to assessing scientific methods*. Chichester: JohnWiley&Sons Ltd; 2004.
96. Amendola A. Recent paradigms for risk informed decision making. 2001;40:17–30.
97. Haskel, Lord, Warner, Lord. *Setting priorities for publicly funded reseach - Volume I: Report*. London; 2010.
98. Antonelli C, Foray D, Hall BH, Steinmueller WE, eds. *New Frontiers in the Economics of Innovation and New Technology: essays in honour of Paul A. David*. Cheltenham: Edward Elgar; 2006.
99. Liebowitz SJ, Margolis SE. The Fable of the Keys. *J Law Econ*. 1990;(October).
100. David PA. Clio and the Economics of QWERTY. *Econ Hist*. 1985;75(2):332–337.
101. David PA. *Path Dependency and the Quest for Historical Economics: one more chorus of the ballad of QWERTY*. Oxford; 1997.
102. Amell TK, Kumar S. Cumulative trauma disorders and keyboarding work. 1999;25.

103. Noyes JAN. The QWERTY keyboard: a review. *Int J Man Mach Stud.* 1983;18:265–281.
104. Wilsdon J, Willis R, Demos. *See-through science : why public engagement needs to move upstream.* London: Demos; 2004:69 p. ; 20 cm.
105. Collingridge D. *Critical Decision Making: a new theory of social choice.* London: Frances Pinter; 1982.
106. Collingridge D. *The Social Control of Technology.* M. Keynes: Open University Pres; 1980.
107. Shaxson L, Harrison M, Morgan M. *Developing an evidence-based approach to environmental policy making : insights from Defra's Evidence & Innovation Strategy.* Brighton; 2009:1–33.
108. Wynne B. Public engagement as a means of restoring public trust in science—Hitting the notes, but missing the music? *Community Genet.* 2006;9:211–220.
109. Wynne B. Risk and Environment as Legitimatory Discourses of. *Curr Sociol.* 2002;50(May):459–477.
110. Wilsdon J, Wynne B, Stilgoe J. *The Public Value of Science: or how to ensure that science really matters.* London; 2005.
111. Pollock N, Williams R. The business of expectations: How promissory organizations shape technology and innovation. *Soc Stud Sci.* 2010;40(4):525–548. doi:10.1177/0306312710362275.
112. Van Lente H. Navigating foresight in a sea of expectations: lessons from the sociology of expectations. *Technol Anal Strateg Manag.* 2012;24(8):769–782. doi:10.1080/09537325.2012.715478.
113. David PA, Rothwell GS. “Standardisation, Diversity and Learning: strategies for the coevolution of technology and industrial capacity.” 1996.
114. Chesbrough H, Vanhaverbeke W, West J, eds. *Open Innovation: researching a new paradigm.* Oxford: Oxford Univ Press; 2006.
115. Blind K. The Impact of Standardization and Standards on Innovation. 2013;(February):1–33.
116. Hughes T. *Networks of Power: electrification in western society 1880-1930.* Baltimore: Johns Hopkins University Press; 1983.
117. Chou C, Shy O. The crowding-out effects of long duration of patents. 2013;24(2):304–312.
118. Hilgartner S. Intellectual Property and the Politics of Emerging Technology: inventors, citizens, and powers to shape the future. *Chic Kent Law Rev.* 2009;81(1):197–224.
119. Porte TR La, ed. *Social Responses to Large Technical Systems: Control or Anticipation.* Dordrecht: Springer; 1991.
120. Kaplinsky R. Globalisation and Unequalisation: What Can Be Learned from Value Chain Analysis? *J Dev Stud.* 2000;37(2):117–146. doi:10.1080/713600071.
121. Winner L. *Autonomous Technology: technics out of control as a theme in political thought.* Camb MASS: MIT Press; 1977.
122. Sabatier P. Social Movements and Regulatory Agencies : Toward a More Adequate and Less Pessimistic Theory of “ Clientele Capture ”*. *Policy Sci.* 1975;6:301–342.
123. Walker W. Entrapment in large technology systems: institutional commitment and power relations. *Res Policy.* 2000;29(7-8):833–846. doi:10.1016/S0048-7333(00)00108-6.
124. Arthur WB. “Competing Technologies, Increasing Returns, and Lock-in by Historical Events.” 1989.
125. Goldacre B. *Bad Science.* London: Harper; 2009.
126. Rowell A. *Green Backlash: Global Subversion of the Environment Movement.* London: Routledge; 1996.
127. Laufer WS. Social Accountability and Corporate Greenwashing. *J Bus Ethics.* 2003;43(Iso 2002):253–261.

128. Krimsky S. *Science in the Private Interest: has the lure of profits corrupted biomedical research*. Oxford: Rowman and Littlefield; 2003.
129. Newman P, Kenworthy J, eds. *Cities and Automobile Dependence, an International Sourcebook*. Aldershot: Gower; 1989.
130. Oreskes N, Conway- EM. *Merchants of doubt: how a handful of scientists obscured the truth on issues from tobacco smoke to global warming*. London: Bloomsbury; 2010.
131. Scrase I, MacKerron G. *Energy for the Future: A New Agenda*. Palgrave Macmillan; 2009.
132. OORWM. *Managing our radioactive wastes safely: CoRWM's recommendations to Government*. London; 2006.
133. Sally C Davies. *Infections and the rise of antimicrobial resistance - Annual Report of the Chief Medical Officer, Volume II*. London; 2011.
134. Stirling A. "Opening Up" and "Closing Down": Power, Participation, and Pluralism in the Social Appraisal of Technology. *Sci Technol Hum Values*. 2008;23(2):262–294.
135. Baulcombe D, Crute I, Davies B, et al. *Reaping the benefits: science and the sustainable intensification of global agriculture*. London: Royal Society; 2009:72p. : illus.
136. BIS. *The Future of Food and Farming: challenges and choices for global sustainability*. London; 2011.
137. IAASTD. *Agriculture at a Crossroads: international assessment of agricultural knowledge science and technology for development (IAASTD)*. Washington: Island Press; 2009.
138. Pretty J. *Agri-Culture: reconnecting people, land and nature*. London: Earthscan; 2002.
139. Wright O. Opponents of third world GM crops are "wicked", says Environment Secretary Owen. *Guardian*. 2013;(October):1–10.
140. HoC. *GM foods and application of the precautionary principle in Europe*. London; 2014:1–7.
141. Poltronieri P, Reza IB. Transgenic, Cisgenic and Novel Plant Products, Regulation and Safety Assessment. In: Poltronieri P, Hong Y, eds. *Applied Plant Genomics and Biotechnology*. Cambridge: Elsevier Woodhead; 2014.
142. Watts S. Genetic moderation is needed to debate our food future. *New Sci*. 2014;(July):8–10.
143. POST. *GM in Agricultural Development.*; 2012:1–4.
144. IRRI. *Scuba rice : breeding flood-tolerance into Asia 's local mega rice varieties*. Manila; 2009:1–6.
145. Jansen K, Vellema S, eds. *Agribusiness and Society: corporate responses to environmentalism, market opportunities and public recognition*. London: Zed Books
146. Benbrook CM. Impacts of genetically engineered crops on pesticide use in the US – the first sixteen years. *Environ Sci Eur*. 2012;24:1–13.
147. Palombi L. *Gene Cartels: biotech patents in the age of free trade*. Cheltenham: Edward Elgar Publishing; 2009. doi:10.4337/9781848447431.
148. FAO. *Save and Grow: a policymaker's guide to the sustainable intensification of smallholder crop production*. Rome: UN Food and Agriculture Organisation; 2011.
149. Leeuwisen C. *Communication for Rural Innovation Rethinking Agricultural Extension*. Oxford: Blackwell; 2004.
150. Lockie S, Carpenter D, eds. *Agriculture, Biodiversity and Markets: livelihoods and agroecology in comparative perspective*. London: Earthscan
151. Altieri MA, Nicholls CI. *Agroecology and the Search for a Truly Sustainable Agriculture*. Colonia Lomas de Virreyes: UNEP; 2005.
152. Uphoff N, ed. *Agroecological Innovations: increasing food productivity with participatory development*. London: Eartscan; 2002.

153. Lichtfouse E. *Climate Change, Intercropping, Pest Control and Beneficial Microorganisms*. Berlin: Springer; 2009.
154. Radcliffe EB, Hutchinson WD, Cancelado RE, eds. *Integrated pest management: concepts, tactics, strategies and case studies*. Cambridge: Cambridge Univ Press; 2009.
155. Sauerborn KMJ. *Agroecology*. Berlin: Springer; 2013.
156. Pretty J, ed. *The Earthscan Reader in Sustainable Agriculture*. London: Earthscan; 2005.
157. Gustavsson J, Cederberg C, Sonnesson U, Otterdijk R van, Meybeck A. *Global food losses and food waste: extent, causes and prevention*. Rome; 2011.
158. Lang T, Heasman M. *Food Wars: the global battle for mouths, minds and markets*. London: Earthscan; 2004.
159. Guyomard H, Moue C Le, Gohin A. Impacts of alternative agricultural income support schemes on multiple policy goals. *Eur Rev Agric Econ*. 2004;31(2):125–148.
160. Sen A. *Development as Freedom*. New York: Knopf; 2000.
161. Stirling A. *Direction, Distribution and Diversity! Pluralising Profess in Innovation, Sustainability and Development*. Brighton; 2010:1–45.
162. Crouch C. *Post Democracy*. London: Polity; 2004.
163. Stirling A. OPENING UP OR CLOSING DOWN? analysis, participation and power in the social appraisal of technology Andy Stirling, SPRU, University of Sussex paper for submission to. *Japan J Sci Technol Soc*. (October 2004):1–35.
164. Stilgoe J. The road ahead. Public Dialogue on Science and Technology. BIS, centre S expert resource, eds. 2009.
165. Stirling A. Pluralising progress: From integrative transitions to transformative diversity. *Environ Innov Soc Transitions*. 2011;1(1):82–88.
166. IPCC. *Renewable energy sources and climate change mitigation: special report of the Intergovernmental Panel on Climate Change*. Cambridge UK: Cambridge Univ Press; 2012. doi:10.5860/CHOICE.49-6309.
167. Nuttall WJ. *Nuclear Renaissance: Technologies and Policies for the Future of Nuclear Power*. Bristol: Institute of Physics Publishing; 2005.
168. Meadowcroft J, Langhelle O, eds. *Caching the Carbon: the politics and policy of carbon capture and storage*. Cheltenham: Edward Elgar; 2009.
169. Shepherd J, Caldeira K, Cox P, et al. *Geoengineering the climate: science, governance and uncertainty*. London: The Royal Society; 2009:82 p. ; 30 cm.
170. Fleming JR. *Fixing the Sky: the checkered history of weather and climate control*. New York: Columbia University Press; 2010.
171. Ridgwell A, Freeman C, Lampitt R. Geoengineering: taking control of our planet's climate. *Sci Sees Furth*. 2012:22–23.
172. Ruddiman WF. *Plows, Plagues and petroleum: how humans took control of climate*. Princeton: Princeton Univ Press; 2005.
173. IPCC WG1. *Fifth Assessment Report: Summary for Policymakers*. Geneva; 2013:1–36.
174. Cairns R, Stirling A. "Maintaining Planetary Systems" or "Concentrating Global Power?" High Stakes in Contending Framings of Climate Geoengineering. *Glob Environ Chang*. 2014.
175. Cairns RC. Climate geoengineering: issues of path-dependence and socio-technical lock-in. *WIREs Clim Chang*. 2014. doi:10.1002/wcc.296.
176. EREC. *Rethinking 2050: a 100% renewable energy vision for the EU*. Brussels; 2010.
177. ECF. *Roadmap 2050: a practical guide to a prosperous, low carbon Europe*. Brussels; 2010.

178. PWC. *100% renewable electricity: A roadmap to 2050 for Europe and North Africa*. London; 2010.
179. WWF. *The Energy Report: 100% renewable energy by 2050*. Gland; 2011.
180. *The Energy Review*. London; 2002.
181. [Pugwash]. *Pathways to 2050 : Three possible UK energy strategies*. London; 2013.
182. ECF. *Roadmap 2050: policy recommendations*.
183. WBGU. *World in Transition Towards Sustainable Energy Systems*. Berlin: German Federal Council on Global Change; 2004.
184. GEA. *Global Energy Assessment Toward a Sustainable Future*. (Davis G, Goldemberg J, eds.). Cambridge UK: Cambridge Univ Press; 2012.
185. Jacobson MZ, Delucchi MA. A Plan to Power 100 Percent of the Planet with Renewables. *Sci Am*. 2009;1–5.
186. Jacobson MZ, Delucchi M a. Providing all global energy with wind, water, and solar power, Part I: Technologies, energy resources, quantities and areas of infrastructure, and materials. *Energy Policy*. 2011;39(3):1154–1169. doi:10.1016/j.enpol.2010.11.040.
187. Delucchi M a., Jacobson MZ. Providing all global energy with wind, water, and solar power, Part II: Reliability, system and transmission costs, and policies. *Energy Policy*. 2011;39(3):1170–1190. doi:10.1016/j.enpol.2010.11.045.
188. King D. David King: Why we have no alternative to nuclear power: if there were other sources of low carbon energy I would be in favour, but there aren't. *Independent*. July 2006:1–4.
189. MacKay DJC. *Sustainable Energy - without the hot air*. Cambridge: UIT; 2009.
190. Rockström J, Steffen W, Noone K, et al. A safe operating space for humanity. *Nature*. 2009;461(September).
191. Devine-Wright P, ed. *Renewable Energy and the Public: from NIMBY to participation*. London: Earthscan; 2011.
192. Lakatos I, Musgrave A, eds. *Criticism and the Growth of Knowledge: Proceedings of the International Colloquium in the Philosophy of Science*. Aberdeen: Aberdeen University Press; 1970.
193. Popper K. *Conjectures and Refutations*. New York: Basic Books; 1962.
194. Stirling A. Let's Hear it For Scepticism. *Res Fortnight*. 2011.
195. Rip A. Controversies as Informal Technology Assessment. *Knowl Creat Diffus Util*. 1987;8(2):349–371.
196. Leach M, Scoones I, Wynne B. *Science and Citizens: globalization and the challenge of engagement*. London: Zed Books; 2005.
197. Garud R, Karnøe P. Bricolage versus breakthrough: distributed and embedded agency in technology entrepreneurship. *Res Policy*. 2003;32(2):277–300.
198. Karnoe P, Jorgensen U. The Danish Wind Turbine Story - Technical Solutions to Political Visions? 1991.
199. Fressoli M, Arond E, Abrol D, Smith A, Ely A, Dias R. When grassroots innovation movements encounter mainstream institutions : implications for models of inclusive innovation. 2014;(July):37–41. doi:10.1080/2157930X.2014.921354.
200. Dryzek JS, Downes D, Hunold C, Schlosberg D. *Green States and Social Movements: environmentalism in the United States, United Kingdom, Germany and Norway*. Oxford: Oxford Univ Press; 2003.
201. Redclift M. *Sustainable Development: exploring the contradictions*. London: Routledge; 1987.
202. Ekins P. *A New World Order: Grassroots Movements for Global Change*.

203. Hess DJ. *Alternative Pathways in Science and Industry: activism, innovation and the environment in an era of globalisation*. Cambridge MS: MIT Press; 2007.
204. Voss J, Bauknecht D, Kemp R, eds. *Reflexive Governance for Sustainable Development*. Cheltenham: Edward Elgar; 2006.
205. Change NE. *Negotiating Environmental Change: new perspectives from social science*. (Berkhout F, Leach M, Scoones I, eds.).
206. Adger WN, Jordan A, eds. *Governing sustainability*. Cambridge: Cambridge University Press; 2009.
207. Fanon F. *Toward the African Revolution*. New York: Grove Press; 1964.
208. Davis DB. *The Problem of Slavery in the Age of Emancipation*. New York: Knopf; 2014.
209. Sudbury J. *Other Kinds of Dreams: black women's organisations and the politics of transformation*. London: Routledge; 1998.
210. Paletschek S, Pietrow-Ennker B, eds. *Women's Emancipation Movements in the Nineteenth Century: a European Perspective*. Stanford: Stanford Univ Press; 2004.
211. Stirling A. *Emancipating Transformations : from controlling ' the transition ' to culturing plural radical progress.*; 2014:1–49.
212. Presidential T, Commission C, Assessment R, Management R. *Risk Assessment and Risk Management In Regulatory Decision-Making*. 1997.
213. IRGC. *An introduction to the IRGC Risk Governance Framework*.
214. HMT. *Managing risks to the public: appraisal guidance*. London; 2005.
215. Porter TM. *Trust in Numbers: the pursuit of objectivity in science and public life*. Princeton: Princeton University Press; 1995.
216. GOS. *Blackett review of high impact low probability events*.
217. Hacking I. *The Emergence of Probability: a philosophical study of early ideas about probability, induction and statistical inference*. 2006.
218. Wolpert L. *The Unnatural Nature of Science: why science does (not) make common sense*. London: Faber and Faber; 1992.
219. Taverne D. *The march of unreason: science, democracy, and the new fundamentalism*. Oxford: Oxford University Press; 2005.
220. Byrd DM, Cothorn CR. *Introduction to Risk Analysis: a systematic approach to science based decision making*. Oxford: Government Institutes Press; 2000.
221. WHO. *Removing Obstacles to Healthy Development*. Geneva; 1999.
222. Suter GW. *Ecological Risk Assessment.*; 2006.
223. Burgman M. *Risks and Decisions for Conservation and Environmental Management*.
224. R.E.Hester, Harrison R, eds. *Risk Assessment and Risk Management*. London: Royal Society of Chemistry; 1998.
225. Lofstedt R. *Reclaiming health and safety for all : Reclaiming health and safety for all : An independent review of*. London; 2011:110.
226. Freemantle N. Does the UK National Health Service need a fourth hurdle for pharmaceutical reimbursement to encourage the more efficient prescribing of pharmaceuticals ? *Health Policy (New York)*. 1999;46:255–265.
227. Jasanoff S, ed. *States of Knowledge: the co-production of science and social order*. London: Routledge; 2004.
228. HSE. *Reducing risks, protecting people: HSE's decision making process*. London; 2001.
229. Boudier F, Slavin D, Lofstedt RE. *The Tolerability of Risk*. London: Earthscan; 2007.

230. ONR. *Safety Assessment Principles for Nuclear Facilities*. London; 2006.
231. Bentkover JD, Covello VT, Mumpower J, eds. *Benefits Assessment: the state of the art*. Dordrecht: Reidel; 1986.
232. O'Brien M. *Making Better Environmental Decisions: an alternative to Risk Assessment*. Cambridge Mass: MIT Press; 2000.
233. Hacking I. *An Introduction to Probability and Inductive Logic*. Cambridge: Cambridge University Press; 2001.
234. Keynes JM, Lewis CI. A Treatise on Probability. *Philos Rev.* 1922;31(2):180. doi:10.2307/2178916.
235. Adams J. *Risk*. London: Routledge; 1995.
236. WHO. *Health and environment: communicating the risks*. Copenhagen; 2013.
237. Renn O, Dreyer M, SpringerLink. *Food safety governance: integrating science, precaution and public involvement*. Berlin: Springer; 2009.
238. Aven T, Renn O. *Risk Management and Governance: concepts, guidelines, applications*. Heidelberg: Springer; 2010.
239. IRGC. *Nanotechnology Risk Governance Recommendations for a global coordinated approach to the governance of potential risks*. Geneva; 2007.
240. RS. *Endocrine disrupting chemicals (EDCs)*. London; 2000.
241. Millstone E, Brunner E, Mayer S. Beyond "substantial equivalence." *Nature*. 1999;401(6753):525–6. doi:10.1038/44006.
242. Stirling AC, Scoones I. From Risk Assessment to Knowledge Mapping: Science, Precaution, and Participation in Disease Ecology. *Ecol Soc.* 2009;14(2).
243. Lewis CI, Keynes JM. A Treatise on Probability. *Philos Rev.* 1922;31(2):180. doi:10.2307/2178916.
244. Knight FH. *"Risk, Uncertainty and Profit."* Boston: Houghton Mifflin; 1921.
245. Rowe WD. *Understanding Uncertainty*. 1994.
246. Wynne B. *Uncertainty and Environmental Learning: reconceiving science and policy in the preventive paradigm*. 1992.
247. Funtowicz SO, Ravetz JR. *Scientific Uncertainty and Quality Evaluation in Technology Scenarios and R&D Programmes*. 1989.
248. Goffman E. *Frame Analysis: an essay on the organisation of experience*.
249. Jasanoff S, Kim S-H. Containing the Atom: Sociotechnical Imaginaries and Nuclear Power in the United States and South Korea. *Minerva*. 2009;47(2):119–146. doi:10.1007/s11024-009-9124-4.
250. Stirling A. Risk at a turning point? *J Environ Med.* 1999;1(3):119–126. doi:10.1002/1099-1301(199907/09)1:3<119::AID-JEM20>3.0.CO;2-K.
251. Thompson M, Warburton M. *Decision Making Under Contradictory Certainties: how to save the Himalayas when you can't find what's wrong with them*. 1985.
252. Shrader-Frechette KS. *Risk and Rationality: philosophical foundations for populist reforms*. Berkeley: University of California Press; 1991.
253. Kelly JS. *Arrow Impossibility Theorems*. New York: Academic Press; 1978.
254. Arrow KJ. *Social Choice and Individual Values*. New Haven: Yale University Press; 1963.
255. MacKay AF. *Arrow's Theorem: the paradox of social choice - a case study in the philosophy of economics*. New Haven: Yale University Press; 1980.

256. Sarewitz D. How science makes environmental controversies worse. *Environ Sci Policy*. 2004;7(5):385–403. doi:10.1016/j.envsci.2004.06.001.
257. Stirling A. Precaution, Foresight and Sustainability: reflection and reflexivity in the governance of science and technology chapter. In: Voss J-P, Kemp R, eds. *Reflexive Governance for Sustainable Development*. Cheltenham: Edward Elgar; 2006:225–272.
258. Loasby BJ. *Choice, Complexity and Ignorance: an inquiry into economic theory and the practice of decision making.* Cambridge: Cambridge University Press; 1976.
259. Stirling A. Risk, Uncertainty and Precaution: Some Instrumental Implications from the Social Sciences. In: Berkhout F, Leach M, Scoones I, eds. *Negotiating Change: new perspectives from the social sciences*. Cheltenham: Edward Elgar; 2003.
260. Faber M, Proops JLR. *Evolution, Time, Production and the Environment*.
261. Zwanenberg P Van, Millstone E. how reassurances undermined precaution. 2000;(11):10–11.
262. Thornton J. *Pandora's Poison: chlorine, health and a new environment strategy*. Cambridge Mass: MIT Press; 2000.
263. Hoffmann MJ. *Ozone Depletion and Climate Change: Constructing a Global Response*. Albany: State University of New York Press; 2005.
264. Randall A. *Risk and Precaution*. Cambridge: Cambridge University Press; 2011.
265. Wynne B. Risk and environment as legitimacy discourses of technology: reflexivity inside out? *Curr Sociol*. 2002;50(3):459–477.
266. Taleb NN. *The Black Swan: The Impact of the Highly Improbable*. New York: Random House; 2007.
267. Brooks H, Cantley] [M. “The Typology of Surprises in Technology, Institutions and Development.” 1986.
268. Rosenberg N. Uncertainty and Technological Change. 1996.
269. Stirling A, European Commission. Joint Research C, Institute for Prospective Technological S, Network E. *On science and precaution in the management of technological risk : an ESTO project report*. [Seville]: European Commission, Joint Research Centre; 2001:142 p. : ill. ; 30 cm.
270. Bertolotti M. *The History of the Laser*. London: Institute of Physics; 1999.
271. Szoka B, Marcus A, eds. *The Next Digital Decade: essays on the future of the internet*. Washington DC: TechFreedom; 2010.
272. Swierstra T, Rip A. Nano-ethics as NEST-ethics: Patterns of Moral Argumentation About New and Emerging Science and Technology. *Nanoethics*. 2007;1(1):3–20. doi:10.1007/s11569-007-0005-8.
273. Stirling A. Risk, uncertainty and power. *Seminar*. 2009;(May 2009):33–39.
274. ESRC. *Science, technology and globalisation*. Swindon
275. Ravetz JR. Usable Knowledge, Usable Ignorance: Incomplete Science with Policy Implications. *Sci Commun*. 1987;9(1):87–116. doi:10.1177/107554708700900104.
276. Jasanoff S. Technologies of Humility: citizen participation in governing science. *Minerva*. 2003;41:223–244.
277. O’Riordan T, Cameron J, Jordan A. *Reinterpreting the precautionary principle*. London: Cameron May; 2001:284 p. : ill. ; 24 cm.
278. Boehmer-Christiansen S. The Precautionary Principle in Germany - enabling Government. 1994.
279. Harding R, Fisher E. *Perspectives on the precautionary principle*. Annandale, N.S.W.: Federation Press; 1999:xvi, 320 p. : ill. ; 25 cm.

280. Fisher E. Precaution, Precaution Everywhere: Developing a “Common Understanding” of the Precautionary Principle in the European Community. *Maastricht J Eur Comp L*. 2002;9:7–28.
281. UNEP. *Rio Declaration on Environment and Development*. Rio de Janeiro, Brazil; 1992.
282. Raffensperger C, Tickner JA. Protecting public health & the environment : implementing the precautionary principle / edited by Carolyn Raffensperger and Joel A. Tickner ; foreword by Wes Jackson. Raffensperger C, Tickner JA, eds. 1999.
283. Marchant G, Mossman KL, eds. *Arbitrary and Capricious: the precautionary principle in the European Union courts*. Washington DC: American Enterprise Institute; 2004.
284. Morris J, ed. *Rethinking Risk and the Precautionary Principle*. London: Butterworth Heinemann; 2000.
285. Goklany IM. *The Precautionary Principle: a critical appraisal of environmental risk assessment*. Washington DC: Cato Institute; 2001.
286. Sunstein CR. *Laws of Fear: beyond the precautionary principle*.
287. Graham JD. The Perils of the Precautionary Principle: Lessons from the American and European Experience. 2004;4999(818).
288. Holm S, Harris J. Precautionary principle stifles discovery. *Nature*. 1999;400(6743):398. doi:10.1038/22626.
289. Martuzzi M, Tickner JA. *The precautionary principle: protecting public health, the environment and the future of our children*. Citeseer; 2004.
290. Beddington J. Addressing the challenges of the 21st century. *FST J*. 2013;21(1):4–7.
291. Stirling A. Deliberate futures: precaution and progress in social choice of sustainable technology. *Sustain Dev*. 2007;15(5):286–295. doi:10.1002/sd.347.
292. Dekkers M, Bock K, Rubsamen H, et al. *The Innovation Principle: stimulating economic recovery*. Vrussels; 2013.
293. Tait J. Upstream engagement and the governance of science: the shadow of the genetically modified crops experience in Europe. *EMBO Rep*. 2009;10:S18–S22.
294. Luj L, Todt O. Analyzing Precautionary Regulation : Do Precaution , Science , and Innovation Go Together ? *Risk Anal*. 2014. doi:10.1111/risa.12246.
295. Felt U, Wynne B, Callon M, et al. *Taking European knowledge society seriously : report of the Expert Group on Science and Governance to the Science, Economy and Society Directorate, Directorate-General for Research, European Commission*. (Felt U, Wynne B, eds.). Brussels: European Commission; 2008:166 p. ; 23 cm.
296. Hopkins MM, Nightingale P. Strategic risk management using complementary assets: Organizational capabilities and the commercialization of human genetic testing in the UK. *Res Policy*. 2006;35(3):355–374. doi:10.1016/j.respol.2005.12.003.
297. Marchant GE, Mossman KL. *Arbitrary and Capricious: the precautionary principle in the European Union courts*. Washington DC: American Enterprise Institute Press; 2004.
298. CEC. *Communication from the Commission on the Precautionary Principle*.; 2000:1–28.
299. Stirling A, ed. *On Science and Precaution in the Management of Technological Risk - Volume II: casestudies*. Sevilla: Institute for Prospective Technological Studies; 2001.
300. Levidow L, Marris C. Science and governance in Europe: lessons from the case of agricultural biotechnology. *Sci Public Policy*. 2001;28(5):345–360.
301. Dreyer M, Renn O, Ely A, Stirling A, Vos E, Wendler F. A General Framework for the Precautionary and Inclusive Governance of Food Safety. 2007.
302. Ravetz J. The post-normal science of precaution. *Futures*. 2004;36(3):347–357. doi:10.1016/S0016-3287(03)00160-5.

303. Stirling A, Gee D. Science, precaution, and practice. *Public Health Rep.* 2002;117(6):521–33.
304. McGlade J, Quist D, Gee D. social responsibility for new technologies. *Nature.* 2013;497(7449):317. doi:10.1038/497317a.
305. Stirling A. Governance of Neuroscience: challenges and responses. In: *Brain Waves: neuroscience, society and policy.* London: Royal Society; 2011:87–98.
306. Stirling A. Risk, precaution and science: towards a more constructive policy debate - Talking point on the precautionary principle. *EMBO Rep.* 2007;8(4):309–315.
307. Saltelli A, Ratto M, Andres T, et al. *Global Sensitivity Analysis: the primer.*
308. Ferson S, Kreinovich V, Ginzburg L, Myers DS, Sentz K. Constructing Probability Boxes and Dempster-Shafer Structures. 2003;(January).
309. Warren-hicks WJ, Hart A, eds. *Application of Uncertainty Analysis to Ecological Risks of Pesticides.* Pensacola: SETAC Press; 2010.
310. Swart R, Bernstein L, Ha-Duong M, Petersen A. Agreeing to disagree: uncertainty management in assessing climate change, impacts and responses by the IPCC. *Clim Change.* 2008;92(1-2):1–29. doi:10.1007/s10584-008-9444-7.
311. Asselt MA van, Rotmans J. Uncertainty in Integrated Assessment Modelling: From Positivism to Pluralism. *Clim Change.* 2002;54:75–105.
312. Petersen AC, Cath A, Hage M, Kunseler E, van der Sluijs JP. Post-Normal Science in Practice at the Netherlands Environmental Assessment Agency. *Sci Technol Human Values.* 2011;36(3):362–388. doi:10.1177/0162243910385797.
313. Ely A, Van Zwanenberg P, Stirling A. Broadening out and opening up technology assessment: Approaches to enhance international development, co-ordination and democratisation. *Res Policy.* 2013;in press. doi:10.1016/j.respol.2013.09.004.
314. Stirling A. Opening Up the Politics of Knowledge and Power in Bioscience. *PLoS Biol.* 2012;10(1):e1001233. doi:10.1371/journal.pbio.1001233.
315. Dovers SR. A framework for scaling and framing policy problems in sustainability. *Ecol Econ.* 1995;12:93–106.
316. Dovers S, Handmer JW. Ignorance, the Precautionary Principle, and Sustainability. *Ambio.* 2013;24(2):92–97.
317. Tickner JA, Wright S. The precautionary principle and democratizing expertise : a US perspective. 2003;30(3):213–218.
318. Fisher E, Jones J, Schomberg R von, eds. *Implementing the precautionary principle: perspectives and prospects.* Edward Elgar Publishing; 2002:155–65.
319. Lujan JL, Todt O. Precaution in public: the social perception of the role of science and values in policy making. *Public Underst Sci.* 2007;16(1):97–109. doi:10.1177/0963662506062467.
320. Rip A. Constructive Technology Assessment. In: Stirling A, ed. *On Science and Precaution in the Management of Technological Risk - Volume II: CaseStudies.* Sevilla: Institute for Prospective Technological Studies; 1999.
321. Lane D, Pumain D, Leeuw SE van der, West G, eds. *Complexity Perspectives in Innovation and Social Change.* Berlin: Springer; 2009.
322. Sadeleer N De. *Implementing the Precautionary Principle: approaches from the Nordic countries, the EU and the USA.* (Sadeleer N de, ed.).
323. Stegmaier BP, Visser VR, Kuhlmann S. Governance of the Discontinuation of Socio-Technical Systems — An Exploratory Study of the incandescent light bulb phase-out. In: *The Governance of Innovation and Socio-Technical Systems in Europe: New Trends, New Challenges - Panel on The governance of innovation and sociotechnical systems: design and displacements.* Vol 2012. Copenhagen; 2012.
324. Weitzman ML. On Diversity. *Q J Econ.* 1992;May.

325. Stirling A. Diversity and ignorance in electricity supply investment: Addressing the solution rather than the problem. *Energy Policy*. 1994.
326. Breznitz S. Educating for coping with change. In: Hamburg D, Frankenheuser M, eds. *Ancient humans in tomorrows electronic world*. Washington DC: Aspen Institute; 1986:32–41.
327. Norgaard RB. *Development Betrayed: the end of progress and a coevolutionary revisioning of the future*. London: Routledge; 1994.
328. Grabher G, Stark D. "Organizing Diversity: Evolutionary Theory, Network Analysis and postsocialism." *Reg Stud*. 1997.
329. James P. "Energy, Environment and Rationality." *Energy Environ*. 1990:114–123.
330. Folke C, Carpenter S, Elmqvist T, Gunderson L, Holling CS. Resilience and Sustainable Building Adaptive Capacity in a World of Transformations. *Ambio*. 2002;31(5):437–440.
331. Rosenberg N. *Inside the Black Box: technology and economics*. Cambridge: Cambridge University Prs; 1982.
332. Nowotny H. Democratising expertise and socially robust knowledge. *Sci Public Policy*. 2003;30(3):151–156.
333. Yoshizawa G, Stirling A, Suzuki T. Multicriteria Diversity Analysis: theory, method and an illustrative application. 2011:211–243.
334. Grubb M, Butler L, Twomey P. Diversity and security in UK electricity generation: The influence of low-carbon objectives. *Energy Policy*. 2006;34(18):4050–4062. doi:10.1016/j.enpol.2005.09.004.
335. Skea J. Valuing diversity in energy supply. *Energy Policy*. 2010;38(7):3608–3621. doi:10.1016/j.enpol.2010.02.038.
336. Stirling A. *Electronic Working Papers Series On the Economics and Analysis of Diversity*.
337. Geels FW, Smit WA. Lessons from Failed Technology Futures: Potholes in the Road to the Future. In: Brown N, Rappert B, Webster A, eds. *Contested Futures A sociology prospective techno-science*. Aldershot Burlington USA Singapore Sydney: Ashgate; 2000:129–156.
338. Stirling A. Energy Research & Social Science Transforming power : Social science and the politics of energy choices. *Energy Res Soc Sci*. 2014;1:83–95. doi:10.1016/j.erss.2014.02.001.
339. Stirling A. Multicriteria diversity analysis A novel heuristic framework for appraising energy portfolios. *Energy Policy*. 2009:1–13. doi:10.1016/j.enpol.2009.02.023.
340. Lawson N. *The View from Number 11: memoires of a Tory radical*. London: Bantam Press; 1992.
341. Stirling A. Multicriteria diversity analysis. *Energy Policy*. 2010;38(4):1622–1634. doi:10.1016/j.enpol.2009.02.023.
342. Felt U, Barben D, Irwin A, et al. *Science in Society: caring for our futures in turbulent times*. Strasbourg; 2013.
343. Brooks EC. Framework for responsible innovation. 2014:2014. Available at: <http://www.epsrc.ac.uk/research/framework/1/1>. Accessed June 29, 2014.
344. Steps Centre. Innovation, sustainability, development : a new manifesto. 2010.
345. BEPA. *Empowering people, driving change: social innovation in the European Union*. doi:10.2796/13155.
346. Stirling A, European Commission. Directorate-General for Research S, Society. *From Science and Society to Science in Society: Towards a Framework for "Co-operative Research."* Luxembourg: Office for Official Publications of the European Communities; 2006:74 p. ; 25 cm.
347. Sclove RE. *Reinventing technology Assessment: a 21st Century Model - using citizen participation, collaboration and expert analysis to inform and improve decision making on issues involving science and technology*. Washington DC; 2010.
348. Leach M, Scoones I, Stirling A. *Dynamic Sustainabilities: technology, environment, social justice*. London: Routledge; 2010.

349. Fiorino DJ. Citizen Participation and Environmental Risk: a survey of institutional mechanisms. 1990.
350. Feyerabend P. *Against Method*. London: Verso; 1975.
351. Bussu S, Davis H, Pollard A. *The best of Sciencewise reflections on public dialogue*. London; 2014.
352. POST. *Open Channels: public dialogue in science and technology*. London; 2001.
353. Mohr A, Raman S, Gibbs B. *Which publics? When? Exploring the policy potential of involving different publics in dialogue around scienc and technology*. London; 2014.
354. Smith G. *Democratic Innovations: designing instituions for citizen participation*.
355. Fischer F. *Democracy and Expertise: reorienting policy inquiry*. Oxford: Oxford Univ. Press; 2009.
356. OECD. *Citizens as Partners: information, consultation and public participation in policy making*. Paris; 2001.
357. Grove-White R, Macnaghten P, Mayer S, Wynne B. "Uncertain World: genetically modified organisms, food and public attitudes in Britain." 1997.
358. Blamey RK, James RF, Smith R, Niemeyer SJ. Citizens' juries and environmental value assessment. *Canberra, Aust Natl Univ*. 2000.
359. Paper SW. Empowering Designs: towards more progressive appraisal of sustainability.
360. Fonseca PFC, Pereira TS. The governance of nanotechnology in the Brazilian context: Entangling approaches. *Technol Soc*. 2013;1–12. doi:10.1016/j.techsoc.2013.07.003.
361. Tornatzky LG, Fergus EO, Avellar JW, Fairweather GW, Fleischer M. *Innovation and Social Process: national experiment in implementing social technology*. (Tonratzky LG, Fergus EO, Avellar JW, Fairweather GW, Fleischer M, eds.). New York: Pergamon; 1980.
362. Wynne B. Public Participation in Science and Technology: Performing and Obscuring a Political–Conceptual Category Mistake. *East Asian Sci Technol Soc an Int J*. 2007;1(1):99–110. doi:10.1007/s12280-007-9004-7.
363. Stirling A. *From Science and Society to Science in Society: towards a framework for co-operative research*. Brussels; 2006.
364. Beck U. *Risk Society: Towards a New Modernity*. London: SAGE; 1992.
365. Stilgoe J, Owen R, Macnaghten P. Developing a framework for responsible innovation. *Res Policy*. 2013. doi:10.1016/j.respol.2013.05.008.
366. Pellizzoni L. Trust, Responsibility and Environmental Policy. *Eur Soc*. 2005;7(4):567–594. doi:10.1080/14616690500194118.
367. Krefting L. Trustworthiness. 1991;45(3):214–222.
368. Editorial. There's no choice: we must grow GM crops now. *The Observer*. March 16, 2014:1–5.
369. Rowell A. *Don't worry [it's safe to eat]: the true story of GM food, BSE and foot and mouth*. London: Earthscan; 2004.
370. Miller D, Dinan W. *A Century of Spin: How Public Relations Became the Cutting Edge of Corporate Power`*. (Miller D, Dinan W, eds.). London: Pluto Press; 2008.
371. Moore a., Stilgoe J. Experts and Anecdotes: The Role of Anecdotal Evidence" in Public Scientific Controversies. *Sci Technol Human Values*. 2009;34(5):654–677. doi:10.1177/0162243908329382.
372. Allan S, Adam B, Carter C. *Environmental risks and the media*. (Allan S, Adam B, Carter C, eds.). London: Routledge; 1999:xiv, 278 p. ; 24 cm.

Recent papers in the SPRU Working Paper Series:

SWPS 2014-12. Anabel Marin, Lilia Stubrin and Patrick van Zwanenberg. June 2014. "Developing capabilities in the seed industry: which direction to follow?."

SWPS 2014-13. Mariana Mazzucato, Carlota Perez. July 2014. "Innovation as Growth Policy: the challenge for Europe."

SWPS 2014-14. Daniele Rotolo , Loet Leydesdorff. July 2014. "Matching MEDLINE/PubMed Data with Web of Science (WoS): A Routine in R language."

SWPS 2014-15. Patrick van Zwanenberg, Erik Millstone. August 2014. "Taste and power: The flavouring industry and flavour additive regulation."

SWPS 2014-16. Steve Sorrell. August 2014. "Energy Substitution, Technical Change and Rebound Effects."

SWPS 2014-17. Martin Binder, Alex Coad. September 2014. "How satisfied are the self-employed? A life domain view."

SWPS 2014-18. Davide Consoli, Francesco Vona, Francesco Rentocchini. September 2014. "That was then, this is now: Skills and Routinization in the 2000s."

SWPS 2014-19. Paul Nightingale, October 2014. "What is Technology? Six Definitions and Two Pathologies."

SWPS 2014-20. Matias Ramirez, Paloma Bernal, Ian Clarke, Ivan Hernandez. October 2014. "Distinguishing patterns of learning and inclusion through patterns of network formation in developing agricultural clusters ."

SWPS 2014-21. Mariana Mazzucato, Caetano R. Penna. October 2014. "Beyond market failures. The market creating and shaping roles of state investment banks."

SWPS 2014-22. Steve Sorrell. October 2014. "Reducing energy demand: A review of issues, challenges and approaches."

SWPS 2014-23. Pablo D'Este, Alberto Marzucchi, Francesco Rentocchini. November 2014. "Exploring and yet failing less: Learning from exploration, exploitation and human capital in R&D."