Chapter 3

The threefold challenge of emerging biotechnologies

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Chapter overview

In this Chapter we identify three characteristics of emerging biotechnologies that give rise to difficulties in emerging biotechnology governance.

The first of these characteristics is **uncertainty** about whether the desired outcomes can be achieved in practice (or the undesirable consequences avoided). We distinguish the radical uncertainty associated with novel and unprecedented emerging biotechnologies from quantifiable risk, and draw out the consequences of this distinction for rational decision making strategies, concluding that early-stage emerging biotechnologies often require an approach characterised by caution and circumspection.

The second characteristic is the **ambiguity** of meaning and value that can apply to emerging biotechnologies, their objects, practices and anticipated outcomes, whereby different people may value the same outcomes differently, but where each of these different judgments has an equal claim to be weighed in decisions that affect those who make them. We examine the challenge that emerging biotechnologies present to moral categories and the implications of this for moral judgment and consider the significance of ideas of 'naturalness' and 'playing God'. This has further consequences for decision making, in terms of how the meaning of harm and benefit is construed, whose 'harms' and 'benefits' are allowed to count and how these are distributed.

The third characteristic is the **transformative potential** of emerging biotechnologies: the capacity to change the way things are done and to open up hitherto unavailable possibilities. We examine the significance of pervasive technological transformations not only to ways of doing but also to ways of thinking and their consequences for how choices are framed.

We note how the characteristics of uncertainty and ambiguity are managed through the framing of decisions about biotechnologies. We acknowledge that, while framing is indispensible in order to achieve progress, the process may result in the suppression of alternative and important values and perspectives or produce distortions, with potentially significant consequences for social life and welfare.

Introduction

3.1 In this Chapter we identify three distinctive characteristics that make governance of emerging biotechnologies especially problematic. The three characteristics are uncertainty, ambiguity and transformative potential.

- By 'uncertainty' we mean an inescapable lack of knowledge about the range of possible outcomes or about the likelihood that any particular outcome will in fact occur. This seriously limits the possibility of accurately forecasting the consequences of decisions with regard to biotechnologies (positive or negative) and similarly limits the effectiveness of prospective efforts to control these outcomes.[172]
- By 'ambiguity' we mean a lack of agreement about the implications, meanings or relative importance of a given range of possible outcomes, irrespective of the likelihood of their occurrence. Ambiguity reveals the association of different and possibly incompatible meanings and values within the practices, products and consequences of biotechnologies.
- By 'transformative potential' we mean the capacity that some emerging biotechnologies may have to transform or displace existing social relations, practices and modes of production, or create new capabilities and opportunities that did not previously exist, or may not even have been imagined. These outcomes might be entirely unexpected or unsought.

[172] Some characterisations of different aspects of problematic knowledge distinguish lack of knowledge of the likelihoods of each outcome in a known range from lack of knowledge about key characteristics of the range of possible outcomes (e.g. the distinction between 'uncertainty' and 'ignorance' in Stirling A (2007) Risk, precaution and science: towards a more constructive policy debate *EMBO Reports* **8**: 309-15). See also paragraph 3.10. This distinction is entirely consistent with the argument made here, but is not essential in order to convey the key implications on which the present discussion is focused.

3.2 Having explored these characteristics, we discuss their implications for decision making and how, in general, decision making processes cope with them. We will argue that failing to attend to the importance of these characteristics can lead to ethically unsatisfactory decision making.

Uncertainty

3.3 Uncertainty is a state of the mind. It describes a lack of knowledge of the real determinants of future states of affairs. Such determinants may be simply too manifold, complex and interdependent to grasp or we may simply lack the means to observe them.[173] To point to deficiencies of knowledge in this way does not imply any view about what intrinsic indeterminacy may be present in natural processes or technological systems. It only entails that the real determinants of future states of affairs cannot be comprehensively understood.

3.4 Lack of empirical knowledge would matter less if a reliable theory or a well-constructed model were available to guide understanding. It matters a lot, however, in circumstances where a model cannot be relied upon, for example because there are novel or unknown factors in play, or vulnerabilities to 'system effects'.[174] This is not only a matter of uncertainties within the underpinning science but of interdependencies in the innovation system that is necessary for the emergence of new biotechnologies, which involves alignments across science, business, politics and society.

Varieties of uncertainty

3.5 Uncertainty regarding practical outcomes and applications is particularly marked in 'early stage' research and in the development of techniques with an indefinite variety of possible applications. DNA synthesis, for example, has practically unlimited potential uses in a wide variety of fields including health, manufacturing and bioremediation, most of which may not be foreseen at present. For any one of these applications, however, different sets of uncertainties attach to the feasibility of applying the technology and its ability to adapt to the conditions of use. Not all promising technologies are easily translated from prototype to large scale production and not all are enthusiastically adopted by users. In fact, the commercialisation rate of patents is low. Estimates vary but it is likely that by far the greater part of patented inventions are never commercialised,[175] and the drop-off in patent renewal rates is a well noted.[176]

3.6 Identifying examples of prospective technologies that fail at an early stage (before patenting or commercialisation) is inherently difficult due not only to the counterfactual nature of the subject but also because of ambiguity about what constitutes both 'failure' and 'technology' in this context. Failure does not necessarily have to reflect an underlying problem with the technical aspects of the product or technique, but may be attributable to other elements of the material context, such as the economic climate, commercial pressures on the developer, or opportunity costs of development.[177]

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[173] This complexity may explain both why biotechnologies present distinctive intellectual challenges and why we may be prone to make 'bad' decisions when confronted with problems of the kind presented by biotechnologies. See, for example, Tversky A and Kahnmann D (1974) Judgement under uncertainty: heuristics and biases *Science* **185**: 1124-31. See also: Cilliers P (2002) Why we cannot know complex things completely *Emergence* **4**: 77-84.

[174] I.e. where the interdependency of elements within systems acts as an exponent of small, local effects, potentially leading to global restructuring. The International Risk Governance Council (IRGC) identifies 'systemic risks', where interdependencies act as risk exponents, as one of the sources of 'emerging risks'. International Risk Governance Council (2012) *A characterisation of emerging risks*, available at: http://www.irgc.org/risk-governance/improving-emerging-risk-management-in-industry/a-characterisation-of-emerging-risks.

[175] There is some debate as to the true extent of the commercialisation of patents: Sichelman, for example, notes a number of studies that give figures of non-commercialisation rates between 40 and 90 per cent, depending on a range of factors: Sichelman T (2010) Commercializing patents *Stanford Law Review* **62**: 341-413.

[176] See: Schankerman M (1991) How valuable is patent protection? Estimates by technology field using patent renewal data *The RAND Journal of Economics* **29**: 77-107.

[177] Such reasons were given in 2011 for Geron's withdrawal from the field of stem cell research. See: Pollack A (2011) Geron is shutting down its stem cell clinical trial *The New York Times* 14 November, available at:

3.7 'Successes' may be as hard to predict as 'failures' and examples of welcome serendipity are common in the history of science and technology. As we noted in Chapter 2, the *origins* of invention seem rarely to be found in *plans* for invention and the uses of resulting inventions are often very different from intended uses.[178] The technique of DNA fingerprinting provides an example: although the forensic implications were very quickly realised, the work that led to the development of the technology was concerned with searching for the human copy of the myoglobin gene (which produces the oxygen-carrying protein in muscle).[179] The prevalence of such cases in the history of technology underlines the value of fostering diversity in invention, and accepting uncertainty in the process rather than constraining it to the delivery of predefined objectives.[180]

3.8 Perhaps the most common concern about novel technologies is the difficulty of predicting the likelihood of unintended and undesirable consequences. This both explains and justifies the regulatory burdens that are placed on the introduction of, for example, new medicinal, industrial and agricultural biotechnology products by most governments. Despite these, examples such as asbestos and chlorofluorocarbons (CFCs) provide sobering examples of the difficulties of prediction and the importance of regulatory learning, particularly with regard to effects that accumulate or manifest only over relatively long timescales.[181] The consequences of technological innovation extend into many different dimensions aside from health and environmental impacts. Among the hardest to predict and control, and the longest to accumulate, may be social consequences, that is, the impact a technology will have on the relationships between individuals and groups in the general population. Many of these are only dimly perceived in advance although their effects may be profound, for example: the social consequences of the internet and the World Wide Web,[182] the influence of the motor car on the design of residential areas (especially in the US),[183] or the way in which the availability of the contraceptive pill has changed working practices and the age at which women first give birth.[184] (We return to the question of foresighting of ethical, legal and social implications in Chapter 6.)

3.9 Alongside unintended consequences, uncontrolled uses provide another dimension of uncertainty. The significance of this is exacerbated by the potential of many biotechnologies for so-called 'dual use' (i.e. with both beneficial and harmful applications), often without further adaptation.[185] For example, the knowledge of how to synthesise flu virus may be used to develop vaccines but may equally be used to develop weapons.[186] However the 'repurposing' of

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http://www.nytimes.com/2011/11/15/business/geron-is-shutting-down-its-stem-cell-clinical-trial.html. However, some have suggested that Geron's overreaching ambition did no favours for the field of therapeutic stem cell research: Boseley S (2011) Geron abandons stem cell therapy as treatment for paralysis *The Guardian* 15 November, available at: http://www.guardian.co.uk/science/2011/nov/15/geron-abandons-stem-cell-therapy.

178 See the classic account in Jewkes J, Sawers D and Stillerman R (1969) *The sources of invention* (New York: WW Norton). For a more recent example, see the apparently inadvertent development of a technique for deriving human embryonic stem cells through parthenogenesis: Mullard A (2007) Inadvertent parthenogenesis *Nature Reviews Molecular Cell Biology* **8**: 677.

179 Newton, G (2004) *Discovering DNA fingerprinting*, available at: http://genome.wellcome.ac.uk/doc_wtd020877.html.

180 The related and important question of when and by what means this diversity should be filtered into desirable innovation pathways – for example, by free markets or other selective mechanisms – is one that we return to later in this Report.

181 For example, the experience of asbestos-related mesotheliomas has encouraged a 'benign by design' approach to the innovations involving carbon nanofibres. (Although the 'benign by design' approach has been at issue in the chemical sciences prior to specifically nanotechnological concerns.) See: Schinwald A, Murphy FA, Prina-Mello A *et al.* (2012) The threshold length for fiber-induced acute pleural inflammation: shedding light on the early events in asbestos-induced mesothelioma *Toxicological Sciences* **128**: 461-70; Newman A (1994) Designer chemistry *Environmental Science & Technology* **28**: 463A.

182 Take, for example, the relatively sudden rise of 'social media' and its influence on the nature of public life. See: Baym NK and Boyd D (2012) Socially mediated publicness: an introduction *Journal of Broadcasting & Electronic Media* **56**: 320-9.

183 For example, the argument that 'urban sprawl' is the result of wide-spread car ownership. See: Glaeser EL and Kahn ME (2004) Sprawl and urban growth, in *Handbook of regional and urban economics, volume 4: cities and geography*, Henderson JV, and Thisse JF (Editors) (Amsterdam: Elsevier).

184 Bailey MJ (2006) More power to the pill: the impact of contraceptive freedom on women's life cycle labor supply *The Quarterly Journal of Economics* **121**: 289-320.

185 Indeed, it has been noted that "all technologies are dual-use. There is no such thing as a technology that cannot be used for evil or malign purposes. Some are closer to weapons, but all of them have that capability". See: Skolnikoff EB (2003) Research universities and national security: can traditional values survive?, in *Science and technology in a vulnerable world: supplement to AAAS science and technology policy yearbook*, Teich A, Nelson S, and Lita S (Editors) (Washington, DC: AAAS), available at: http://www.aaas.org/spp/yearbook/2003/stvwch6.pdf, p69.

186 This led to a voluntary moratorium on the publication of relevant research and a vigorous debate that reached the national media in early 2012. See Box 3.1.

technologies may also be relatively benign and is, in fact, reasonably common, from off-label use of drugs such as 'Avastin'® (bevacizumab) – normally used to treat cancers – to treat the eye condition wet age-related macular degeneration more cheaply than the relevant National Institute for Health and Clinical Excellence-approved drug,[187] to the cosmetic use of neurotoxins such as botulinum toxin (as 'Botox'®).[188] The uncertainties with regard to repurposed technologies are, once again, compounded by ambiguities: one state's 'defence' programme can be construed by another as a threat, for example.[189]

Box 3.1: Repurposing biotechnologies: potential misuse of H5N1 research

Avian influenza (influenza A) is a naturally occurring genus of the influenza virus that is maintained in wild birds but also affects commercial and pet birds and can (rarely) infect mammals. There are multiple sub-types of the influenza A virus which can be divided into viruses of high and low pathogenicity. It is difficult for avian influenza viruses to infect humans, but in 1997 the highly-pathogenic influenza A virus sub-type H5N1 emerged in Hong Kong and transmitted to humans, in some cases fatally. In 2003-4 another outbreak began in south-east Asia; during the period 2003- 2012, the World Health Organization (WHO) recorded a total of 608 cases and 359 deaths.[190] Although H5N1 does not, currently, naturally transmit by aerosol between humans, it remains a major global public health concern as it "might develop the capacity to sustain human-to-human transmission and, thereby, spread worldwide".[191]

Not surprisingly, a great deal of research has been carried out on this virus. In particular, in 2011, two pieces of research ignited "a firestorm of debate".[192] The work, by two separate groups in the US and the Netherlands, contained detailed information regarding alternations of the influenza A H5N1 viruses rendering it capable of mammal-to-mammal transmission by aerosol,[193] and that the relevant mutations were few.[194] The work prompted the US National Science Advisory Board for Biosecurity (NSABB), which was concerned about the 'dual-use' implications of the work (i.e. that the data could allow terrorists to create biological weapons), to recommend censorship of research in this area: delay in publication, redaction of the details of how the virus was modified to allow mammal-to-mammal transmission and observance of a two month moratorium on similar research until the risks were assessed.[195] Although the recommendations of the NSABB are theoretically non-binding, both *Science* and *Nature* (the journals in which the research was to be published) agreed to the delay publication and the scientists involved agreed to a voluntary moratorium.[196] In March 2012, the NSABB concluded that revised versions of the manuscripts by the research groups should be published. Both pieces have now been published.[197]

The original recommendation to delay and redact the papers generated a fierce debate about the conduct and dissemination of dual-use research.[198] Indeed, the entire episode is a good example of how (in this case, potential) uncontrolled use of technologies can influence lines of research and the development of particular technologies: the work highlighted differences in the values different groups applied to the issue and in their approach to calculating potential benefits and harms of a particular technological development. Although such issues are not clear-cut, there was evident (if not surprising) divergence between the scientific community and the security community in terms of the value of openness and transparency, at least during the early stages of the controversy: the WHO argued that "redaction…is not viable";[199] there were "months of wrangling that pitted advisory board against scientists".[200] The principal investigator from the Netherlands noted that "in dual-use research, weighing risks and benefits of the research is the crux…Reaching consensus among scientific disciplines, let alone among the public at large, is virtually impossible."[201]

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187 See: NICE (2010) *Department of Health asks NICE to look into Avastin use for eye conditions*, available at: http://www.nice.org.uk/newsroom/news/DHasksNICEtolookintoAvastinuseforeyeconditions.jsp.
188 See: del Maio M and Berthold R (2007) *Botulinum toxin in aesthetic medicine* (Berlin: Springer).
189 Any ostensibly 'defensive' biological weapons research demonstrates this kind of ambiguity.
190 See: WHO (2012) *Cumulative number of confirmed human cases for avian influenza A(H5N1) reported to WHO, 2003-2012*, available at: http://www.who.int/influenza/human_animal_interface/EN_GIP_20120810CumulativeNumberH5N1cases.pdf.
191 Briand S and Fukuda K (2009) Avian influenza A (H5N1) virus and 2 fundamental questions *Journal of Infectious Diseases* **199**: 1717-9.
192 Roehr B (2012) US board says censuring research on avian flu was necessary to prevent a potential catastrophe *BMJ* **344**: e840.
193 Hayward P (2012) H5N1 research put on hold *The Lancet Infectious Diseases* **12**: 186-7.
194 Hawkes N (2012) WHO recommends further delay in journals publishing research on bird flu *BMJ* **344**: e1284.
195 Hayward P (2012) H5N1 research put on hold *The Lancet Infectious Diseases* **12**: 186-7.
196 Enserink M (2012) Public at last, H5N1 study offers insight into virus's possible path to pandemic *Science* **336**: 1494-7.
197 Imai M, Watanabe T, Hatta M *et al.* (2012) Experimental adaptation of an influenza H5 HA confers respiratory droplet transmission to a reassortant H5 HA/H1N1 virus in ferrets *Nature* **486**: 420-8; Herfst S, Schrauwen EJA, Linster M *et al.* (2012) Airborne transmission of influenza A/H5N1 virus between ferrets *Science* **336**: 1534-41.
198 The Lancet Infectious Diseases editorial (2012) Avian influenza and the dual-use research debate *The Lancet Infectious Diseases* **12**: 167.
199 WHO (2012) *Technical consultation on H5N1 research issues - consensus points*, available at: http://www.who.int/influenza/human_animal_interface/consensus_points/en/index.html.
200 Hayward P (2012) H5N1 research unleashed, almost *The Lancet Infectious Diseases* **12**: 368-9.
201 Fouchier RAM, Herfst S and Osterhaus ADME (2012) Restricted data on influenza H5N1 virus transmission *Science* **335**: 662-3.

Uncertainty and risk

3.10 There are significant differences of terminology in the relevant literature regarding knowledge of the future. For the purposes of this Report, we distinguish situations where we face *uncertainty* – where the range of possible outcomes or the relative likelihood of each cannot be determined with reasonable confidence – from situations where outcomes can be characterised and probabilities assigned to them with meaningful levels of confidence. (Some commentators make the further distinction within what we have called ‘uncertainty’ according to whether the range and likelihood or just the likelihood of possible outcomes cannot be defined.)[202]

3.11 In situations in which outcomes can be confidently characterised and probabilities assigned, quantitative risk analysis may usefully inform decision making. Situations of uncertainty, by contrast, may include ‘unknown unknowns’ of which we become more aware as technology emerges.[203] In such circumstances, risk analysis is unhelpful and attempts to apply it may be dangerously misleading. The significance of the distinction lies in the possibility of being mistaken about where the limits of our knowledge lie: the relevant distinction is not the conceptual one between uncertainty and risk but the practical one about when awareness of the limits of our knowledge leads us to approach decision making in a different way.

3.12 The decision between ‘risk approaches’ and ‘uncertainty approaches’ is actually quite a straightforward matter of confidence in a particular assignment of probability. This may be high, for example, where there is believed to exist a large and long-established body of relevant data, where conditions are expected to remain the same, or where models are fairly robust. Such conditions often apply in areas like well-understood occupational health risks from chemical exposure, the epidemiology of familiar pathogens, or transport safety on long-established infrastructures. Nonetheless, it can often be a matter of judgment as to whether a particular body of knowledge adequately supports a risk approach to a given situation or whether it involves more intractable uncertainty. Such judgments are important for questions of governance: normative theories of decision making distinguish different ‘rational’ strategies for decisions approached as risk and those confronted as uncertainty, for example, privileging caution over goal-seeking.[204]

Ambiguity

3.13 The second characteristic that we associate with emerging biotechnologies is ambiguity. Ambiguity exists when a single phenomenon is capable of bearing two (or more) incompatible meanings. Unlike uncertainty – which refers to the *impossibility* of determining in advance what outcomes will result from following particular biotechnology trajectories – the difficulty to which ambiguity gives rise is that of reaching a *coherent understanding* or evaluation of the prospects, practices or products of emerging biotechnologies in a way that can support decision making.

[202] Our distinction follows that given in Elster J (1983) *Explaining technical change* (Cambridge: Cambridge University Press and Universitetsforlaget). However, Stirling, for example, distinguishes *risk* (outcomes can be identified and probabilities assigned), *uncertainty* (outcomes can be identified but probabilities not confidently assigned), *ambiguity* (the issue is not probabilities – the event in question may already have occurred - but the definitions and interpretations of outcomes) and *ignorance* (there is confidence neither about probabilities nor outcomes). (Stirling A (2007) Risk, precaution and science: towards a more constructive policy debate *EMBO Reports* **8**: 309-15). Tannert, Elvers and Jandrig present a taxonomy based on their ‘igloo of uncertainty’ which separates open and closed knowledge and uncertainty. (See: Tannert C, Elvers H-D and Jandrig B (2007) The ethics of uncertainty *EMBO Reports* **8**: 892-6.)

[203] Perhaps the most famous description of this was contained in an answer to a question at a press conference given by the (then) US Secretary of Defence, Donald Rumsfeld: “The message is that there are [k]no[wn] ‘knowns.’ There are thing[s] we know that we know. There are known unknowns. That is to say there are things that we now know we don’t know. But there are also unknown unknowns. There are things we don’t know we don’t know. So when we do the best we can and we pull all this information together, and we then say well that’s basically what we see as the situation, that is really only the known knowns and the known unknowns. And each year, we discover a few more of those unknown unknowns.” Rumsfeld D (6 June 2006) *Press conference by US Secretary of Defence, Donald Rumsfeld*, available at: http://www.nato.int/docu/speech/2002/s020606g.htm.

[204] For the significance of this judgment for rational decision theory, see, for example: Elster J (1983) *Explaining technical change* (Cambridge: Cambridge University Press and Universitetsforlaget), p185ff.

Ambiguous visions

3.14 In a modern plural society it is almost inevitable that different social groups will have divergent interests and values, and emerging biotechnologies have a particular capacity to polarise these. What look like significant benefits to some (for instance, promises of 'life extension'), may often appear to others, equally reasonably, as worrisome threats (for instance: overpopulation, socially debilitating age profiles, or growing inequality). The issue of whose values and understandings prevail has been taken up forcefully by feminist writing in bioethics.[205] In a democratic society or, indeed, any system that respects the right of individuals and groups to determine their own values and interests, it is an important question how these different understandings of the nature of 'harm' and 'benefit' will weigh in any decision that affects them all.

3.15 Likewise, ideas of what constitutes the *scope* of 'harm' or 'benefit' may differ significantly. For example, the effects of genetically modified (GM) crops may be understood in terms of food safety, environmental impact, global trade, agronomic practice, farmer livelihoods, corporate concentration, property rights, the political economy of food as a whole, or the fundamental relations between humanity and nature. In this example, socially responsible policy making may take into account several of these perspectives; regulation typically considers only the first three – and especially the first.

3.16 A third difficulty lies in determining an ethically and socially fair distribution of these multi-dimensional, differently valued, short- and long-term harms and benefits across different populations or social groups.[206] How much should be gained by particular 'winners' before the impact on specific 'losers' can be justified, if at all, and how should the 'losers' be compensated? How can different valuations be integrated in a decision making procedure? Which, if any, may be set aside? Ambiguity is thus relevant not just to narrow risk-based appraisal of emerging technologies, but also to any notion of ethics-based governance.

Ambiguous practices

3.17 Whereas the ultimate outcomes of emerging biotechnologies may be more speculative, the novelty of practices and products of biotechnologies can be challenging for established forms of understanding or evaluation. This novelty leads to ambiguity about the nature of what is involved in biotechnology, whether it is continuous with previous practice or qualitatively different in some important way (for example, whether and, if so, in what ways, marker-assisted breeding – or induced mutagenesis, or genetic engineering – are importantly different from traditional plant breeding). These ambiguities have been articulated in ways that draw attention to the question of whether biotechnologies involve crossing some 'line' that is invested with ethical importance, and therefore whether the practices involved should be subject to a separate ethical judgment.

3.18 One way in which objections to some biotechnologies have been expressed is through the accusation that practitioners are 'playing God', implicitly crossing a line between forms of agency that are acceptable and those that are improper. Such objections have been levelled, for example, at the creation of an organism with a synthetic genome by the J. Craig Venter Institute. The 'playing God' accusation is one way of expressing unease or dissatisfaction with

[205] See, for example, the articles in *Bioethics* **15**(3),as summarised by the guest editors' note of that edition: Diniz D and Donchin A (2001) Guest editors' note *Bioethics* **15**: iii–v.

[206] See, for example, Beck U (1992) *Risk society: towards a new modernity* (London: Sage); Renn O, Webler T and Wiedemann P (Editors) (1995) *Fairness and competence in citizen participation: evaluating models for environmental discourse* (Dordrecht: Kluwer); Rayner S and Cantor R (2006) How fair is safe enough? The cultural approach to societal technology choice *Risk Analysis* **7**: 3-9.

the apparently untrammelled pursuit of technical advances. As commentators have noted, it may mean different things to different people and stand in for other kinds of concern.[207]

Box 3.2: 'Artificial' life and 'playing God'

In 2010, the J. Craig Venter Institute published in the journal *Science* an article describing how one of its research teams (of which Ventner was a part) were able to design, synthesise and assemble a *Mycoplasma mycoides* genome before transplanting it into a *Mycoplasma capricolum* recipient cell to create new *M. mycoides* cells "controlled only by the synthetic chromosome".[208]

The possibility of creating this kind of cell has prompted a significant amount of commentary on both technical and ethical implications of the work, including a Report of the US Presidential Commission for the Study of Bioethical Issues, published in response to the work at the J. Craig Venter Institute.[209]

Regarding the technical implications, it has been argued that the methods used by Venter and his colleagues allow not only for a search of a minimal organism, but also the ability to "investigate the physiological, ecological, and evolutionary consequences of inserting genes… [with] the potential to engineer large introductions of never-before transferred and unlinked genetic material in synthetic cells… to explore completely novel ecological diversity in bacteria".[210] Venter himself has argued that the work has the potential to usher in "a new industrial revolution".[211]

Ethical commentary on the possibility of creating 'artificial' life has focused in particular on the moral status of relevant organisms and whether or not the creators of such organisms are effectively 'playing God'.[212] Some have argued that the scientists involved were 'playing God' as a consequence of "seeking total and unrestrained control over nature";[213] others note that that they were "'playing God'…much more effectively than earlier genetic engineers…[by] not just tinkering with life, [but] designing and creating it",[214] but also point out that "for many of us, this is not a problem." Other commentators have argued that, notwithstanding the technically impressive nature of the work, the methods used by Venter and his team did not constitute 'creating life'.[215]

Ambiguous objects

3.19 A related way in which biotechnologies may disturb established categories upon which judgments may often rely (at least as a starting place for moral reflection) is through the generation of novel objects. Animals produced by chimerism or transgenesis containing human genetic material,[216] human admixed embryos[217] or embryos reconstructed through mitochondrial transfer,[218] protocells with a synthetic biochemistry not previously seen in nature,[219] extreme

[207] See, for example, Douglas T and Savulescu J (2010) Synthetic biology and the ethics of knowledge *Journal of Medical Ethics* **36**: 687-93.

[208] Gibson DG, Glass JI, Lartigue C *et al.* (2010) Creation of a bacterial cell controlled by a chemically synthesized genome *Science* **329**: 52-6.

[209] Presidential Commission for the Study of Bioethical Issues (2010) *New directions: the ethics of synthetic biology and emerging technologies*, available at: http://www.bioethics.gov/documents/synthetic-biology/PCSBI-Synthetic-Biology-Report-12.16.10.pdf. See also: Thompson PB (2012) Synthetic biology needs a synthetic bioethics *Ethics, Policy & Environment* **15**: 1-20.

[210] Cohan FM (2010) Synthetic genome: now that we're creators, what should we create? *Current Biology* **20**: R675-R7.

[211] BBC News Online (2010) *'Artificial life' breakthrough announced by scientists* available at: http://www.bbc.co.uk/news/10132762.

[212] See, for example, Baertschi B (2012) The moral status of artificial life *Environmental Values* **21**: 5-18; Sandler R (2012) The value of artefactual organisms *Environmental Values* **21**: 43-61.

[213] Dr David King, director of Human Genetics Watch, quoted in Alleyne R (2010) Scientist Craig Venter creates life for first time in laboratory sparking debate about 'playing god' *The Telegraph* 20 May, available at: http://www.telegraph.co.uk/science/7745868/Scientist-Craig-Venter-creates-life-for-first-time-in-laboratory-sparking-debate-about-playing-god.html.

[214] Douglas T (2010) Venter creates bacterium controlled by a synthetic genome on *Practical ethics* [internet blog] 20 May, available at: http://blog.practicalethics.ox.ac.uk/2010/05/venter-creates-bacterium-controlled-by-a-synthetic-genome.

[215] See, for example, Professor Steven Rose writing in *The Guardian*: Rose S (2010) Craig Venter is not playing God yet *The Guardian* 24 May, available at: http://www.guardian.co.uk/science/2010/may/24/venter-not-playing-god-yet. A spokesman for the Vatican argued that, rather than creating life, the experiment simply "replaced one of its motors". See: CNN (2010) *Vatican calls synthetic cell creation 'interesting'*, available at: http://www.cnn.com/2010/HEALTH/05/22/vatican.synthetic.cell/index.html?hpt=T3.

[216] See: Academy of Medical Sciences (2011) *Animals containing human material*, available at: http://www.acmedsci.ac.uk/download.php?file=/images/project/Animalsc.pdf, p70ff.

[217] See: HFEA (2007) *Hybrids and chimeras*, available at: http://www.hfea.gov.uk/docs/Hybrids_Report.pdf.

[218] See: Nuffield Council on Bioethics (2012) *Novel techniques for the prevention of mitochondrial DNA disorders: an ethical review*, available at: http://www.nuffieldbioethics.org/mitochondrial-dna-disorders.

[219] Bedau MA and Parke EC (Editors) (2009) *The ethics of protocells: moral and social implications of creating life in the laboratory* (Cambridge, Massachusetts: MIT Press).

human enhancement and ‘transhumanism’,[220] and superintelligent computers[221] are all concepts, realised or proposed, that challenge at least some conventional ways of separating objects into categories that are invested with value (organism/artefact; human/non-human; born/made, natural/artificial, etc.)

3.20 The reason that such categories are important is that they often form the basis of moral judgments or the possibility of a system of positive laws. As such, the problems they create may have legal as well as moral consequences where, for example, legal certainty may be necessary in order for research and development of new technologies to progress, or to be brought to a halt definitively. A striking example of this relates to research on cloned or human admixed embryos, which brought about disputes over legal interpretation and debates around enabling legislation.[222]

Taking ambiguity seriously

3.21 There are at least two reasons for taking seriously the implications of ambiguity discussed here. The first is procedural fairness, which includes the requirement that contrary views should not be refused consideration without good reason. Of course, admitting multiple standards of value makes rational decision making difficult. Indeed, long-established findings in rational choice theory[223] show that (especially in a plural society) the notion of a uniquely ‘rational’ choice for a society is not only difficult in practice but is, in many senses, a contradiction in terms.[224] The second is that failing to take the implications of ambiguity seriously may simply displace or defer the *consequences* of ambiguity. These may then find other forms of expression that may nevertheless influence the emerging biotechnology trajectory in other ways. Such consequences may include the loss of public confidence or trust in particular technological commitments, and also in associated institutions and research disciplines. More widely, the use of narrowly-conceived ‘evidence-based’ decision making procedures employing methodological formalism but excluding wider societal and political considerations can erode confidence in the impartiality of scientific advice and policy making.[225] Perhaps the most familiar example of this is the experience with GM crops in Europe over the past 20 years. Here, it is widely accepted – including by industry bodies that initially supported the introduction of these products – that the intensity of the public backlash was, in part, due to the exaggeration of the role of science in essentially political matters of technology governance.

220 See, for example, Bostrom N (2009) Why I want to be a posthuman when I grow up, in *Medical enhancement and posthumanity*, Gordijn B, and Chadwick R (Editors) (Dordrecht: Springer), also available at: http://www.nickbostrom.com/posthuman.pdf and Bostrom N (2005) A history of transhumanist thought *Journal of evolution and technology* **14**: 1-25.

221 In particular, the notion of a ‘technological singularity’ expressing the overtaking of human intelligence by intelligence not of solely biological origin. See, for example, the influential paper presented by Vernor Vinge in 1993: Vinge V (1993) *The coming technological singularity: how to survive in the post-human era*, available at: http://www-rohan.sdsu.edu/faculty/vinge/misc/singularity.html and Kurzweil R (2005) *The singularity is near: when humans transcend biology* (New York: Viking).

222 On cloned embryos, see: *R. v. Secretary of State for Health ex p. Quintavalle (on behalf of Pro-Life Alliance)* [2003] UKHL 13; on admixed embryos, see: HFEA (2007) *Hybrids and chimeras*, available at: http://www.hfea.gov.uk/docs/Hybrids_Report.pdf.

223 Rational choice theory can be considered – at the broadest level – as an attempt to understand behaviour by combining “the advantages of theory-guided research, as found in economics, with the strong empirical tradition of sociology.” Lindenberg S (1992) The method of decreasing abstraction, in *Rational choice theory: advocacy and critique*, Coleman JS, and Fararo TJ (Editors) (Newbury Park, California: Sage).See also: Scott J (2000) Rational choice theory, in *Understanding contemporary society: theories of the present*, Browning G, Halcli A, and Webster F (Editors) (London: Sage).

224 The economist Kenneth Arrow demonstrated the impossibility of any voting system converting the ranked preferences of individuals into a group ranking without simultaneously violating at least one apparently reasonable criterion of fairness. See: Arrow KJ (1950) A difficulty in the concept of social welfare *Journal of Political Economy* **58**: 328-46.

225 An argument elaborated in Mayer S and Stirling A (2004) GM crops: good or bad? *EMBO Reports* **5**: 1021.

Transformative potential

Technical change and disruptive technologies

3.22 The ways in which new technologies come to be adopted and, eventually, supplant previous technologies has been an important area of theoretical interest to social scientists and, in particular, economists. A number of models have been proposed to explain technology choice behaviour by societies, entrepreneurs and consumers.[226] They offer different explanations of the phenomena of unevenness in technology change (particularly within industry), which tends to be characterised by relatively stable phases during which a dominant technology is in widespread use (and enjoys incremental improvement) and often destabilising transitions to new dominant technological forms. What are now conventionally described as ‘disruptive technologies’,[227] are novel technologies that are not incrementally linked to existing technologies but that are capable of bringing novel products to market that are cheaper, simpler and more convenient to use than the conventional technologies, or that are capable of developing new markets that did not exist previously.[228] We are therefore concerned with two consequences of technological change (although this distinction is not always clear-cut): first, the ability to perform functions that were already being performed by established technologies but radically more efficiently; second, performing functions that were not possible at all before the appearance of the new technology.

3.23 As shown by the fact that it took over a hundred years to introduce and develop steam engine – perhaps the epitome of a transformative technology – the benefits of transformative technologies may take some time to become established. Perhaps the clearest example of revolutionary technological change (novel technologies becoming pervasive in a short time) is semiconductor-based technologies.[229] However, it may be a mistake to frame our expectations of the pace and linearity of biotechnology innovations by the experience of semiconductors, and even less so our expectations of their measureable impact.[230] The gradient and continuity of innovation is important because it has implications for policy and the profile of resource allocation over time.[231]

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[226] Among the most well-known is the ‘rational choice’ model of neoclassical economics, the ‘wave model’ associated with Joseph Schumpeter, evolutionary and Marxian models. A helpful survey is provided by Elster J (1983) *Explaining technical change* (Cambridge: Cambridge University Press and Universitetsforlaget).

[227] We consistently prefer the term ‘transformative’ to ‘disruptive’. This avoids any unhelpful negative connotation of the term ‘disruptive’, but, more importantly, suggests the thoroughgoing way in which novel technologies may reconfigure a domain of dependent possibilities not limited to the economic register.

[228] Christensen CM (1997) *The innovator's dilemma: when new technologies cause great firms to fail* (Cambridge, Massachusetts: Harvard Business School Press).

[229] Semiconductor materials are the basis of transistors, diodes and all integrated circuits and – as such – modern computing.

[230] The increasing computational power of semiconductor technologies is often described as conforming to the famous ‘Moore’s law’, which predicts the exponential rise in the density of transistors that can be placed on an integrated circuit (doubling every two years). Nevertheless, it is not the performance of the technology that is relevant but its conditions of innovation. Paul David makes a related point about the complexity and timescale of economic impacts of technology, reflecting on the quip, attributed to Robert Solow, that “We see computers everywhere but in the economic statistics.”

[231] See: Hopkins MM, Martin PA, Nightingale P, Kraft A and Mahdi S (2007) The myth of the biotech revolution: an assessment of technological, clinical and organisational change *Research Policy* **36**: 566-89. The authors conclude: “It may well be better to allocate a greater proportion of resources to other activities, which offer more immediate health gains (e.g., the better adoption of existing ‘low tech’ technologies with a proven track record of safety and efficacy). Our analysis also undermines the idea that the biotech sector will play a key role in economic growth or regional development through the rapid creation of thousands of new, high-technology jobs.”

Box 3.3: The steam engine

The steam engine transformed industrial production in 19th Century Britain, and brought significant improvements to the efficiency of production, as well as extending the possibilities for future products. The steam engine overcame 'hard constraints', making power both portable (based on abundant coal rather than water or wind), and highly efficient (using a highly-concentrated energy source that overcame the hard constraint that limited all previous technologies). This constraint arose from the limits on power density available to previous non-fossil fuel energy sources, which ultimately comes from the rate of arrival of solar power on the earth; preindustrial economies depended on biomass fuel, human and animal power (derived from crops), and renewable sources such as wind and water power (both of which are secondary effects of solar radiation). In comparison to other countries, England was unusual in that the transition to fossil fuel energy happened very early; by 1650, energy from coal already surpassed that of firewood.[232]

However, while the use of coal and steam eventually became pervasive – at least until the arrival of more advanced engines using fossil fuels – it took some time to supplant earlier technologies. This was due to the poor efficiency of steam engines until the late 1800s, combined with the high price of coal as a result of the low technology then applied to its extraction. However, the efficiency of steam power and coal mining improved throughout the 19th Century, and these developments reduced the cost of steam power generally.[233]

Although steam power has arguably become the epitome of a transformative technology, when its impact is measured as a cost/output saving over other sources of industrial power during the early industrial revolution in Britain, it turns out to be much less significant – and less significant for much longer – than its cultural prominence suggests.[234] Long after the innovation of steam engine, however, other technologies continued to advance and to be used alongside it (for example, water power, where water was available as a power source) and, of course, still are. This comparison with counterfactual possibilities rather than with stalled incumbent technologies has been examined by some economic historians, leading to a reassessment of the comparative economic contribution of steam power in specific contexts.[235] Although some of the results of the 'new economic history' are controversial among economists, they point to an important way of posing questions about prospective technologies, taking into account their comparative developmental potential and the importance of the innovation context as well as simple technical superiority.

3.24 By 'transformative potential', we mean something more than simply functional advantage (in terms of speed, cost and efficacy) in achieving certain objectives or extending the range of objectives that can be achieved. Indeed, a technology may be transformative without offering such advantages, that is, it may transform modes of behaviour without making them 'better'[236] at least by some standards. What we mean by transformative potential is the capacity of biotechnologies to supplant existing or alternative modes of practice so thoroughly, that these become marginalised, obscured or even inaccessible. This outcome is a result of the processes of 'lock-in' and 'path dependency' that we have described (see paragraphs1.24 to 1.26 and 1.30 to 1.33), but which, by operating systemically – overrunning both practice and discourse – institutes a new 'paradigm' or technological regime. This regime is one that simultaneously transforms the criteria by which technologies of its kind are evaluated and, eschewing the goals or problems that were the focus of previous regimes, sets new goals and new problems for technology.[237]

3.25 What we are describing, therefore, is a transformation both in ways of *thinking* and in the scope of *practical possibilities* for what we have referred to as the discursive and material contexts

232 Wrigley EA (2010) *Energy and the English industrial revolution* (Cambridge: Cambridge University Press). By 1850, to meet the energy consumption of England and Wales from firewood would have required almost the whole land area to be forested. This could not have happened, of course, so this level of energy consumption was only possible because that constraint had been lifted through the use of coal.

233 See: Tylecote A (1992) *The long wave in the world economy: the current crisis in historical perspective* (London: Routledge), pp36-70.

234 Von Tunzelmann N (1977) *Steampower and British industrialisation to 1860* (Oxford: Oxford University Press).

235 See, for example, analyses in the vein of the 'new economic history' pioneered by Robert Fogel. Fogel reassessed the comparative impact of steam railways to the transportation of agricultural products in the US in the 19th Century to a few percentage points of gross domestic product; see: Fogel R (1964) *Railroads and American economic growth: essays in econometric history* (Baltimore, Maryland: Johns Hopkins University Press). See also: Fogel RW (1966) The new economic history: its findings and methods *Economic History Review* **19**: 642-56.

236 Such as the 'rational design' approach to drug discovery. See: Hopkins MM, Martin PA, Nightingale P, Kraft A and Mahdi S (2007) The myth of the biotech revolution: an assessment of technological, clinical and organisational change *Research Policy* **36**: 566-89. See also Chapter 1.

237 The notion of a 'technological paradigm' was developed in technology studies literature to support evolutionary explanations of both continuous and discontinuous technical change, notably by Giovanni Dosi (see: Dosi G (1982) Technological paradigms and technological trajectories: a suggested interpretation of the determinants and directions of technical change *Research Policy* **11**: 147-62). Most definitions in the literature imply, saliently, that the paradigm defines the domain of what counts as a relevant or important problem, even to the extent of obscuring and excluding appreciation of other problematics.

(see paragraphs 1.19 to 1.23). Frequently, the discursive transformation may pre-empt the material transformation. This does not mean that pervasive benefits should not be expected from the currently forecast 'revolutions' in biotechnology. Nor, importantly, does it mean that this present discourse of transformation will have been inconsequential in relation to whatever transformations may occur in future. Indeed, it may have a significant effect, which is why we argue that special attention should be given to this discourse. What we must attend to in developing an ethics of emerging biotechnologies, and what our methodological scepticism questions, is the possibility of research and innovation being caught up in an anticipatory paradigm, one that shores up the 'biotechnology wager', by committing particular social objectives to biotechnological solutions and, in some cases, to particular prospective technologies.

Framing emerging biotechnologies

3.26 The characteristics of emerging biotechnologies we have discussed appear to bring us to a point of more fundamental scepticism. Uncertainty and ambiguity undermine the rational bases for decision making. How, after all, can a decision be made about what conditions to put in place in order to support a biotechnology – or biotechnology generally – if one cannot determine the likelihood of it providing a benefit that is sought or if one cannot be sure that what is sought is even a benefit at all? How can the value of alternatives that exist outside the paradigm that circumscribes value be considered? Yet conditions such as funding, institutions, and regulatory procedures, are routinely put in place, apparently in the aid of realising sometimes very specific outcomes from technological initiatives. We now examine how uncertainties and ambiguities may be managed, and, in the next Chapter, identify the elements of an ethical approach to doing so.

The idea of a 'frame'

3.27 Decisions about the conditions that influence the direction of biotechnology research, development and innovation arise in different contexts. However, all emerge against a background of knowledge, beliefs and values that give a particular significance to different possible options. Arguing for one set of conditions against another implicitly or explicitly invokes this background as a reason for preferring it to the available alternatives. We describe this background as a 'frame'.[238] For instance, a firm may think of funding the development of a new product because it has expertise in that area and believes it can return a profit, but its criteria may be limited to those that are relevant to the market, and not, for example, the social impact of the product. That product may privilege a particular range of consumers or produce a comparative disadvantage for others. How those consumers see the product may, on the other hand, depend very much on those factors.

3.28 Frames may be coextensive with more or less coherent technical perspectives (for example, academic disciplines or particular paradigms within – or transecting – these). Individual actors may approach decisions by first, perhaps unconsciously, selecting an appropriate frame through which to interpret the phenomena in question.[239] While frames may be connected with, and determine, the quality of individual subjective experience, we use this concept in this Report to denote a phenomenon of public discourse rather than individual psychology. Thus one frame may be shared by a number of people and one person may interpret a single phenomenon in a variety of ways depending on the frame that they apply to it.

3.29 Framing is indispensible to understanding the social meaning of biotechnologies, as it is to the understanding of any social phenomenon: it responds to the complexity of facts and values in play by filtering, organising and ascribing relevance to them. Two important considerations lie

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238 The sociological concept of the frame derives from the work of Goffman; see: Goffman E (1986) *Frame analysis* (Boston, Massachusetts: Northeastern University Press).

239 This question of attaching meaning to social phenomena is the one with which Goffman initiates his inquiry: "I assume that when individuals attend to any current situation, they face the question: "What is it that's going on here?" Whether asked explicitly, as in times of confusion and doubt, or tacitly, during occasions of unusual certitude, the question is put and the answer to it is presumed by the way the individuals then proceed to get on with the affairs at hand." (p8.)

behind this: firstly, a frame is always necessary to give phenomena significance; secondly, there is no 'universal' or 'absolute' frame that would synthesise every possible meaning or value. From this it follows that all frames are incomplete, that alternative framings are always possible, and that it is rarely self-evident that any one frame should be privileged over alternatives.

3.30 Nevertheless, in relation to many familiar social phenomena, specific aspects of frames may be well-established and widely shared. For example, in a society with common cultural and religious traditions, and commitments to human rights, common value frameworks contribute to making the everyday behaviour of individuals relatively consistent and predictable, within certain limits. If it were not for the way that frames are embedded in public discourse, a pernicious relativism might be inescapable. Consistent moral frames also allow a given individual to make consistent choices over time and – importantly – to assimilate novel phenomena.[240] However, frames are also dynamic; whatever their innate conditions of possibility, they are subject to reconfiguration and learning in response to novel challenges.

3.31 The importance of considering alternative frames in the governance of emerging biotechnology is heightened by the fact that so many social processes operate in the real world effectively to 'close down' the plurality of frames that may be applied. These processes are often typical of routine decision making processes where institutional bias or 'groupthink' are found.[241] This does not imply that alternative frames may not coexist with the dominant frame, or only that they are not 'granted' equal status to influence outcomes.[242] Governance processes that do not effectively mitigate such pressures may foreclose the range of frames through which emerging biotechnologies are understood and evaluated. Evidence-based policy making, often concerned with formalised assessment of impact and risk, is a common mitigation but, as we argued in Chapter 1,[243] with emerging biotechnologies there are significant difficulties in applying evidence, a conclusion that has led to our more sceptical and reflective approach. In the next two sections, we describe the role of frames in suppressing the uncertainty and ambiguity associated with emerging biotechnologies.

Uncertainty reduced to risk

3.32 As we have argued above, one convenient simplification effected by framing is to bring phenomena subject to uncertainty and ambiguity within a context that supposes the possibility of a rational preference. As a consequence, decisions may be guided by a misplaced confidence in the relevance of an evidence base, risk management methodology and quantification. Likewise, the significance of ambiguity may be repressed through social processes of aggregation and consensus.

3.33 However, even at the limit of full confidence in the identification of outcomes and the assignment of likelihoods of each, it has been shown that decision making is not immune from the effects of presentation, manipulation of language, individual psychology and group dynamics.

3.34 The findings of psychological research have shown that human subjects, when confronted with risk, make choices that are not consistent with calculative rationality,[244] that the framing of choices tends to affect this in certain ways and, in some cases, that the 'framing effect' can be

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240 See: Plous S (1993) *The psychology of judgment and decision making* (New York: McGraw-Hill).

241 For example, the methods by which the Royal Air Force prosecuted its bombing campaign during the Second World War, or the interpretation of intelligence relating to weapons of mass destruction during the lead up to US-led invasion of Iraq in 2003. See: Edgerton D (2008) *The shock of the old* (London: Profile), p13-4 and US Select Committee on Intelligence (2004) *Report of the Select Committee on Intelligence on the U.S. intelligence community's prewar intelligence assessments on Iraq, together with additional views*, available at: http://www.intelligence.senate.gov/108301.pdf, p18.

242 This does not imply any deliberate intention to dominate or mislead. It may come about, for example, by means of individual prejudice, selective resourcing, expedient design, organisational incentives, economic interests, and associated patterns of advancement, preferment and patronage.

243 See Box 1.2.

244 See the work of Tversky and Kahneman, discussed in paragraphs 2.41, 3.3 and 4.13.

measured. They do not show that framing effects are consistent or universal.[245] However, they do demonstrate a malleability in human agents faced with complex situations that is sufficient to conclude that framing has a significant, if not wholly predictable or reproducible, effect.

Box 3.4: Framing effects

Research on the influence of psychological factors on the outcome of decisions made under determinate risks noted how, when the same facts were presented to research subjects in different ways, and all other things being equal, their choices tended to be influenced by the mode of presentation.[246] The authors noted that it is a common pattern that choices presented as possible gains produce risk-averse decisions, where as choices presented as possible losses produce risk-taking decisions, whether those losses or gains are in terms of money, time or human lives lost or saved. The difference between these outcomes is explained as the 'framing effect'.

In one of the most frequently cited examples, when research subjects were presented with alternative preparations for an outbreak of 'an unusual Asian disease' that was expected to kill 600 people, when the alternatives were presented in terms of lives saved a significant majority chose the certain gain (200 lives saved) over the more risky option (1/3 probability that 600 people will be saved and 2/3 probability that 600 people will die), even though it represented an equal expected value. However, when the same choice was presented in terms of lives lost a similarly significant majority chose the more risky programme (1/3 probability that nobody will die and 2/3 probability that 600 people will die) over the certain loss (400 deaths).[247]

The authors identified a number of psychological phenomena that are relevant to decisions under uncertainty and the way in which we use evidence. Their 'availability heuristic', for example, may explain the point made in Chapter 1 about the optimism bias that arises as a result of examples of successful technologies being more available to recall than failed ones.[248]

Ambiguity reduced to univocality

3.35 Another effect of framing is to limit the dimensions of ambiguity by restricting the range of different types of relevant consideration. Thus, if a question to be determined is considered to be a purely technical matter, choices will be focused on the best way of meeting technical standards rather than other kinds of normative standard.[249] This may mean, for example, that the collateral or long term costs are not adequately represented, or unintended consequences are not adequately considered. In contexts framed by economic values, long term social consequences may also receive little consideration. If economic activity is a poor proxy for the welfare of populations, encouraging entrepreneurialism and commercial activity offers no guarantee that public interests will be served. Nevertheless, there is abundant evidence, particularly since the economic downturn, of a foregrounding and privileging of economic framings in research policy.

3.36 The dominance of a particular technological paradigm also limits consideration of alternative technological pathways that may offer a different, but equally feasible, mix of costs and benefits. Where the set of criteria of 'success' of the technology progressively adapts to the actual outcomes of research, feedback between the discursive determination of criteria for 'technological success' and the material conditions of technological progress becomes self-reinforcing and self-justifying.[250]

Conclusion

3.37 The uncertainties and ambiguities of emerging biotechnologies, and their potential to transform not only methods of production and the range of things produced but also ways of thinking and

245 Druckman JN (2001) Evaluating framing effects *Journal of Economic Psychology* **22**: 91-101.

246 Tversky A and Kahneman D (2007) The framing of decisions and the psychology of choice *Science* **211**: 453-8. The paper concludes: "When framing influences the experience of consequences, the adoption of a decision frame is an ethically significant act."

247 Ibid.

248 See Tversky A and Kahneman D (1973) Availability: a heuristic for judging frequency and probability *Cognitive Psychology* **5**: 207-32 and other works by those authors referred to in paragraphs 2.41, 3.3 and 4.13.

249 For example the way in which "FSA policy is determined only by sound science" in relation to genetically modified foods: see BBC News Online (2010) *Academic quits GM food committee*, available at: http://www.bbc.co.uk/news/10229106.

250 Collingridge describes this as the *conservation of technology* effect (Collingridge D (1980) *The social control of technology* (Milton Keynes: The Open University Press), p139); Rip's promise-requirement cycle exhibits a similar dynamic.

valuing, argue that there is a need for a more sceptical and reflective approach to the framing of decisions that shape their emergence. When we think about emerging biotechnologies, it is important to think about *how* we think about them. The challenge of uncertainty and ambiguity does not mean that there can never be a basis for distinguishing better options from worse. It is not framing itself that is the problem, since it is indispensible, but *how* decisions are framed in terms of the kinds of normative questions that are treated as most important. The framing of decisions is especially important in emerging biotechnologies in light of the need to manage high levels of uncertainty and ambiguity.

3.38 Economics and wider social science offer insights into specific mechanisms through which real-world markets and institutions can readily end up favouring technological options that are manifestly problematic and may even be economically suboptimal. More insidiously, the pursuit of technical or economic standards may favour technologies that entrench and even widen social divisions. It matters, therefore, that we recognise the uncertainties involved in governing biotechnologies, and that we approach them not with a misplaced confidence in calculated risks and benefits, but with caution and circumspection, and set within the broader context of social values and objectives.