For publication in the journal *Futures* 39(4), 2007

GM Crops on Trial:
Technological Development as a Real-World Experiment

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Abstract

Through the European controversy over agricultural biotechnology, genetically modified (GM) crops have been evaluated for an increasingly wide range of potential effects. As the experimental phase has been extended into commercial practices, the terms for product approval have become more negotiable and contentious. To analyse the regulatory conflicts, this paper links three theoretical perspectives: issue-framing, agri-environmental discourses, and technological development as a real-world experiment.

Agri-biotechnological risks have been framed by contending discourses which attribute moral meanings to the agricultural environment. Agri-biotech proponents have emphasised eco-efficiency benefits which can remedy past environmental damage, while critics have framed 'uncontrollable risks' in successively broader ways through ominous metaphors of environmental catastrophe. Regulatory authorities have translated those metaphors into measurable biophysical effects. They anticipate and design commercial use as a 'real-world experiment', by assigning greater moral-legal responsibility to agro-industrial operators who handle GM products.

Expert-regulatory debate reflexively considers the social discipline necessary to prevent harm, now more broadly defined than before. Official procedures undergo tensions between predicting, testing and prescribing operator behaviour. In effect, GM crops have been kept continuously 'on trial'.

Contents

1 Introduction

Through the European controversy over agricultural biotechnology, GM crops have been kept on continuous trial. Their symbolic status has been disputed – e.g., as an environmentally-friendly improvement in plant breeding, or as a risk-management problem, or as pollutants in themselves. These products have been put on trial also in the scientific-managerial sense, as regards what risks must be tested and managed, as well as what responsibilities should be assigned to agro-industrial operators.

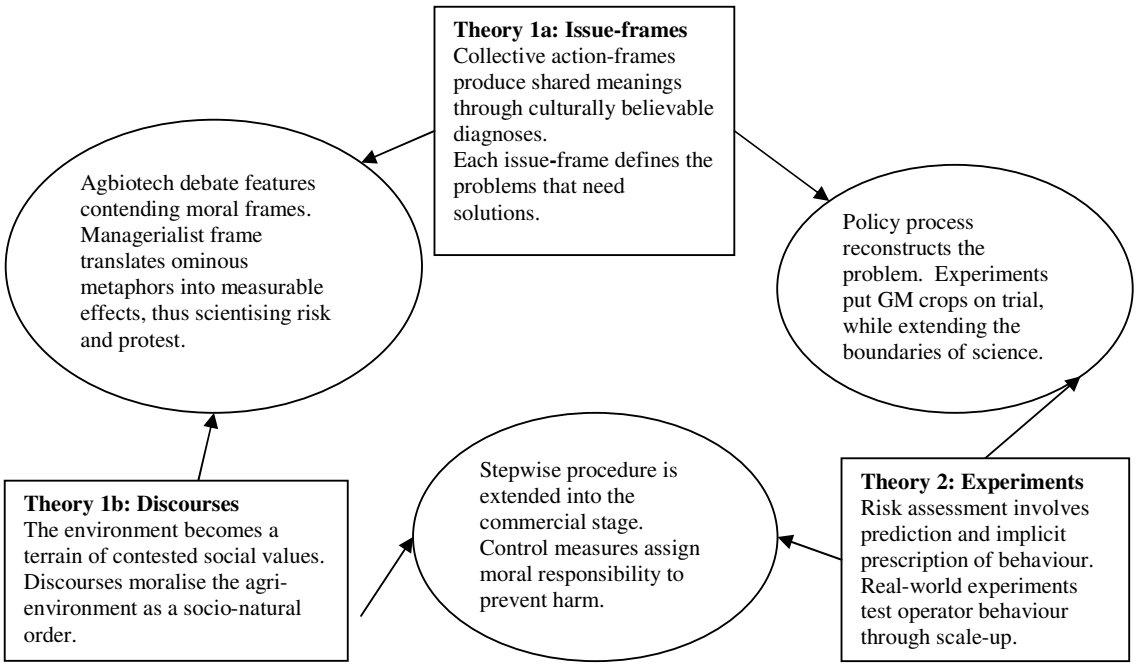
This paper analyses how regulatory procedures have disputed and tightened the basis for commercial approval of GM products. This analysis has two main stages:

- how biotechnological risks have been framed by contending discourses, in turn leading regulatory authorities to extend their responsibility for potential effects of GM products; and
- how commercial contexts have been simulated or designed as experiments for testing such effects and preventive measures.

This paper first sketches relevant theoretical perspectives and then applies them to the case study. For research methods, see the Acknowledgements section.

Diagram 1: Links among Theoretical Perspectives in the Case Study

Note: Arrows indicate how theoretical perspectives (in boxes) are linked through the analysis (in circles)



2 Theoretical perspectives

For an overview of the paper, Diagram 1 sketches how the analysis will link the three perspectives, as presented here in their own right. The first sub-section combines Theories 1a and 1b, i.e. issue framing and agri-environmental discourses. The subsequent sub-section presents Theory 2, technological development as a real-world experiment.

2.1 Contending discursive frames of agri-environmental issues

In policy debate, contending frames define the societal problems that need solutions, argues Surel [1] (see Diagram 1, theory 1a, top). When social movements seek policy change, they devise 'collective action frames'. These help to produce shared meanings of issues, to mobilise adherents and resources, and thus to use or create new political opportunities for influence. Resonance with public meanings depends less upon whether discursive claims have factual validity than upon whether they offer culturally-believable diagnoses of societal problems, argue Benford and Snow [2].

Issue-framing has been widely analysed for agri-environmental discourses (see Diagram 1, theory 1b, lower left-hand corner). European agriculture has been given diverse environmental meanings. The wider countryside has been portrayed, for example, as an aesthetic landscape, a wildlife habitat, refuge from urban industry, local heritage, etc. – which agriculture may endanger or preserve. Such framings have justified government policies which variously support farmers or discipline them so as to protect the environment.

National agrarian beliefs have idealised agriculture in various ways. In the UK since the early 1990s, farmers have been portrayed as stewards who conserve the landscape. This image has helped to justify government subsidies on a new basis. In response, environmental campaigners have demanded that the government substantiate its claims for that stewardship role [3]. Such pressures have left farmers more vulnerable to criticism, demands and discipline.

Since the mid-1990s, the UK government has portrayed farm waste as environmental 'crime', a concept which attaches blame and thus moralises risk. Livestock effluent has been portrayed as 'agricultural pollution', i.e. as matter out of place, thus justifying laws which impose greater responsibility upon farmers [4]. Moral visions are attached to the proper social ordering of the agro-environment; the 'polluter pays' principle assigns responsibility for disorderly run-off of pesticides and fertilisers [5]. Government promotes technical solutions to the overall agrochemical problem, while environmentalists criticise these remedies as unrealistic and as unable to halt the 'pesticide treadmill', given its systemic causes [6].

In analogous ways, contending frames of agricultural production arose in the controversy over bovine growth hormone, designed to increase milk production. Both sides appealed to accounts of the natural, even by naming the product in different ways. The euphemistic term 'bovine somatotropin' implied a natural basis for a benign productive efficiency. For critics, the term 'hormone' implied an unnatural chemical, by analogy to other capital-intensive innovations which had already harmed environmental quality, small-scale farming and its independence [7].

In general, environmentalist movements have recast 'nature' as a realm of purity, morality and fragility. Speaking in such terms, they have reinvented the 'global environment' as an urgent issue. They have portrayed environmental change as a serious global threat to be remedied or averted – by contrast to mainstream policy frameworks, which treat the environment as resources warranting expert management [8].

Catastrophic environmental change is more readily foreseen in the recent historical context, where industrialisation has destroyed not only 'nature' but also the nature/society dichotomy, argues Ulrich Beck. As nature becomes ever more a casualty and an elusive historical product, its injuries are defined in diverse scientific, counter-scientific and socio-cultural ways. At least implicitly, society debates the possible future of 'nature' as framed by culture, e.g. through technological capacity to mitigate past damage:

> Modernisation risks are the scientised 'second morality' in which negotiations are conducted on the injuries of the industrially exhausted ex-nature in a socially legitimate way, that is, with a claim to effective remedy [9].

As risks are translated into scientifically measurable terms, e.g. for measuring or remedying harm, societal conflicts 'lead to forms of scientisation of the protest against science' [10].

This process opens up plural cognitive frameworks for anticipating and controlling risks. In cases where uncertainty and decision stakes are high, the stereotypical distinction between hard facts and soft values is readily inverted. Soft facts become dependent upon hard values [11].

In particular, 'the environment' has become a terrain of contested social values, as Maarten Hajer argues. Although environmental threats are often attributed to nature, they are always framed by policy agendas, through story-lines which selectively problematise some aspects of physical and social reality. Narrative devices include images, causal models and metaphors. Environmental discourses define problems and structure reality so that some framings seem plausible, while others are foreclosed. Rules which constitute the social order have no inherent power; rather, 'they have to be constantly reproduced and reconfirmed in actual speech situations, whether in documents or in debates' [12]. Each problem-definition implies a future scenario for ordering nature, society and technology.

Contending frames drive policy conflict and change. Often environmental change is turned into a public issue through apocalyptic discourses emphasising the fragility of nature, also a metaphor for social or economic vulnerability. Pollution discourses portray industrial activities as immoral, social disorder [13].

The above perspectives can mean that an issue involves two frames, but some environmental controversies feature interactions among multiple frames, each with its own discourse of the socio-natural order. As a prominent schema along those lines, Cultural Theory analyses any controversy as three main political cultures, each promoting its own 'myth of nature', in turn justifying preferred social relations. In particular, an individualist culture frames nature as benign – providing a cornucopian source of societal benefits, while restoring global equilibrium. A hierarchist culture frames nature as 'perverse/tolerant', able to correct any perturbations within finite limits, beyond which it undergoes serious harm. An egalitarian culture frames nature as ephemeral, inherently vulnerable to harm. Each frame justifies policies which would licence, constrain or forbid industrial activities, respectively [14].

Likewise this paper analyses European conflicts over agbiotech as three contending frames: eco-efficiency, managerialist and apocalyptic (see Table 1). Our schema draws upon the three categories of Cultural Theory, though without supposing that the concomitant social relations are 'preferred' ones. Through a managerialist frame, extra control measures extend operator responsibility and experimental designs for a controversial technology.

2.2 Technological development as a real-world experiment

Technological development can be analysed through the following questions: In scaling up a technology, how are potential risks anticipated and tested in the real world? What practices operate as experiments? For those general questions, some theoretical perspectives will be sketched in their own right, before applying them to the case study.

Concepts of risk have shifted – 'from technological, to socially constructed, to post-normal, to modernist, to a means through which society envisages its future'. There is greater 'pressure-group activism on political and economic decision makers', so that risk conflict is driven beyond any objective increases in risk. Recognising those changes, new risk paradigms have the aim 'of achieving closer proximity to real-world risk problems' [15].

Regulatory science is normally devised and validated within cost constraints. This means clearly distinguishing between merely 'nice to know' versus 'need to know' information for regulatory decisions [16]. Such information depends upon standard contexts and assumptions of product use, which are not so readily predictable and often become contentious.

As a small-scale method to anticipate any risks, a laboratory test generally has strong boundary conditions for isolating the inside from its wider environment and thus for controlling variables. On the one hand, this containment can ensure that any unexpected effects are negligible or reversible. On the other hand, lab tests have inherent limitations for anticipating any wider potential harm, so the resulting knowledge may have little relevance to everyday discourse and practice outside science [17]. According to Krohn and Weyer, the practical relevance of lab tests depends on bridging the gap between the two contexts:

> … if scientific knowledge is to be 'applied' in society, then either the existing boundary conditions for laboratory science must be adapted to those of society, or societal practice must be changed according to the standard set for laboratory science [18].

In practice, both those tendencies can operate simultaneously, by extending laboratory methods into larger-scale technological development (see Diagram 1, theory 2, lower right-hand corner). A 'real-life experiment' can test social assumptions through hypotheses about potential effects, controlled variation of parameters and an organised research process. Extending the normal limits of experimental science, however, means losing control over the boundary conditions. Science is unaccustomed to 'the dilemma of the responsibility for the risks emerging from such experiments' [19].

To fulfil that broader responsibility, 'Risks entailed by interaction with the environment can only be investigated by means of implementation on the scale of the real world'. If harm results, then it would be publicly unacceptable (and illegitimate) for the experimenters to blame human failure, unforeseen disturbances or unknown side-effects; such explanations would reveal weaknesses in the scientific disciplines involved. Consequently, when science extends its disciplinary boundaries, 'it becomes increasingly involved in negotiations concerning the conditions for the performance of experiments in and on society' [20]. After this theoretical framework was first published in German, the key term *Realexperimente* was initially translated as real-life experiment and later as real-world experiment, which emphasises the wide range of actors involved. A couple examples from Germany can illustrate the practical meaning.

In negotiating local waste management, for example, the design process explicitly tested and managed human behaviour. After a toxic waste site was found underneath a housing development in Bielefeld, public protest led to demands for a provisional way of planning a new site for waste disposal. Rather than propose a specific plan, a new approach devised three criteria: repairability of faults, controllability to allow shutdown in an emergency, and retrievability of the contents. These criteria were accommodated by an interim plan, so that the initial operation could gain more knowledge about whether human and technical components would behave as intended. As a result, 'the parameters of risk analysis could be checked in a real-life implementation'. This approach was able 'to take seriously the experimental character of the introduction of technology and to make the process socially transparent' [21].

Waste disposal methods too have been developed through real-world experiments. Early methods were modelled on a closed-cycle economy, dependent on greater recycling, which generated new environmental hazards. Criticisms led to alternative proposals. Municipal authorities have sought ways to change and control the burden of household waste, in ways appropriate to new disposal methods. Through a recursive learning process, 'The experimental design tends to shift from purely instrumental to socio-technological experimentation' [22].

Moreover, such a process can help to legitimise socio-technical change:

> Negotiations take place between different stakeholders and 'citizen scientists' who participate as fully valued actors with respect to goals and management of surprises stemming both from social and natural systems… As real-world experiments are often part of the public's everyday life, involvement of the public can deliver a more robust legitimation basis [23].

Of course, any technological system is effectively experimental, in terms of testing assumptions about intended, unintended and even unanticipated effects. More profoundly, safety depends upon implicit social models of human behaviour. As cited above, a high-profile controversial example is bovine growth hormone: when veterinary experts advised on its safety, their judgement assumed that farmers would always use the drug under specified conditions. Nuclear safety too depends on assumptions that operators' judgements are reliable and trustworthy, with high stakes for harmful consequences. Thus, according to Brian Wynne, safety depends on social norms:

> Indeed, the articulation of a risk assessment in real life becomes in effect a prescriptive framework for the technology, as the social assumptions underlying the risk assessment take on the role of tacit commitments that must prevail to validate the technology (and the assessment) [24].

Likewise regulatory procedures involve assumptions about 'how society must be organised so that the technology will behave in accordance with established risk assessments'. Such assumptions underpin the 'grand social experiment' of negotiating technologies [25].

3 Expanding the regulatory scope for GM crops

In the risk debate on GM crops, there has been a societal conflict about how to define the 'harm' which must be prevented. This section analyses how contending discourses generated greater controversy, attributing moral meanings to risks and benefits. Consequently, some governments expanded the regulatory scope for potential effects of GM crops. To analyse the changes which ensued, this section draws on theoretical perspectives about risk framings (Diagram 1, left-hand side).

3.1 Contending risk frames of agri-biotech

As mentioned earlier, the agbiotech debate can be analysed as three contending risk frames: eco-efficiency, managerialist and apocalyptic (see Table 1). Each portrays dangers and opportunities in ways which favour a specific future for society. Each gives different moral meanings to agro-environmental change. Such agri-biotech discourses originated in the 1980s, though this survey emphasises more recent examples.

[insert Table 1]

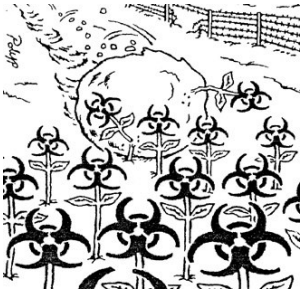
From its eco-efficiency frame, the agri-biotech industry has promoted GM crops as modest, benign extensions of selective breeding. It has diagnosed the societal problem as inefficient agricultural inputs, which can be remedied by more efficiently reaping nature's cornucopian potential through agri-biotech. GM crops bring environmental, agronomic and economic benefits. In particular, herbicide-tolerant and pest- and disease-resistant plants are more economical for the farmer, as well as environmentally beneficial, according to an industry association [26].

According to this eco-efficiency discourse, such multiple benefits strengthen societal responses to more intense market competition. GM crops bring future benefits which overcome present problems:

> EuropaBio asks legislators to consider biotechnology as a part of the toolkit that will help European agriculture develop a more harmonious balance between food production and our surrounding environment. Evidence that GM crops are good for the environment and for the competitiveness of agriculture is mounting in those parts of the world that are already growing GM crops [27].

Exemplifying this frame, the picture below depicts the double helix as a productive money tree, rewarding its investors [28].

In the apocalyptic frame, by contrast, GM crops pose risks which lie beyond credible management. Early on, critics attacked agri-biotech for aiming 'to convert agriculture into a branch of industry' [29]. According to environmental NGOs, GM technology aggravates the problems of intensive agriculture. Its products bring unpredictable, uncontrollable risks, while increasing farmers' dependence on commodity inputs and multinational companies. Exemplifying this frame, the picture below depicts GM crops as pollutants which therefore must be 'decontaminated' [30].



According to an apocalyptic discourse, agri-biotech also undermines benign alternatives, in particular, less-intensive agricultural methods and high-quality products. Representing mainly smaller-scale farmers, the *Coordination Paysanne Européene* advocates extensification measures, based on 'remunerative agricultural prices and sustainable family farming, with multiple benefits for society' [31]. Such farmers oppose GM crops as an industrial threat of greater dependence on multinational companies [32]. In France, the most prominent affiliate has emphasised threats to peasant expertise and livelihoods, rather than environmental risk [33]. In an analogous way, small-scale farmers in Italy have opposed GM crops as a threat to *prodotti tipici*, local specialty products.

Since the late 1980s agri-biotech critics have popularised a series of ominous risk metaphors (see Diagram 1, lower-right corner). Early on, critics emphasised the prospect of a 'genetic treadmill', by analogy to the pesticide treadmill of pests developing resistance to chemical insecticides. For example, GM herbicide-tolerant crops would spread the tolerance trait to related plants, and increased herbicide usage would favour the resistance trait, leading to 'superweeds'; likewise pest-resistant GM crops would generate resistant pests. Since the mid-1990s critics warned that broad-spectrum herbicides would 'sterilise' farmland

biodiversity important for wildlife habitats. More recently they have popularised alarm about 'genetic pollution', as an environmental threat which would also deny consumers a choice to buy 'pure' non-GM products.

New accounts of nature and its injuries followed from the three ominous metaphors – superweeds, sterilisation and GM pollution. These metaphors associated GM crops with environmental dangers, even immoral behaviour, thus putting agri-biotech symbolically on trial. These discursive frames helped to mobilise activists and to intensify public suspicion towards agri-biotech.

In response to that conflict, a managerialist frame has sought to legitimise EU regulatory procedures through links between scientific evidence and extra-scientific issues. According to the European Commission, its regulatory framework

> … aims to provide a high level protection of human health and the environment, legal certainty for operators, address public concerns, including ethical concerns, facilitate consumers' choice, and thereby fosters further public confidence on the use of GMOs [34].

However, 'science-based regulatory oversight' is 'the expression of societal choices' regarding biotechnology: rules should ensure that market mechanisms function effectively, so that safe products become available to accommodate consumer preferences [35]. This policy burdens risk regulation with high stakes for how risk is framed. The rest of this section sketches how regulatory criteria eventually scientised the three ominous metaphors from the risk controversy, thus mediating between eco-efficiency and apocalyptic frames.

3.2 Broadening regulatory criteria

For regulating agri-biotech, 1990 EC legislation was designed to manage and clarify uncertain risks of each GM product before the commercial stage. Covering the environmental risks of GMOs, the Deliberate Release Directive 90/220 (henceforth the Directive) mandated a case-by-case system of formal risk assessments and consents for R&D field trials at national level, as a possible basis for market approval at the EU level. Each member state must avoid 'adverse effects to the environment and human health' from GM organisms [36]. Adverse effects were not specified in the legislation, so their definition depended on interpreting specific cases, initially prior to any significant public debate in most EU member states.

In the mid-1990s safety claims regarded some potential undesirable effects as not 'adverse effects' or as not relevant to regulation of GM crops. By contrast, some member states proposed that the risk assessment encompass a wider range of potential effects, in particular, genetic-treadmill scenarios of insect resistance and herbicide-tolerance. Some also proposed that the risk assessment consider how herbicide-tolerant crops would involve a switch to broad-spectrum (or 'total') herbicides, which kill all other vegetation, thus potentially harming farmland biodiversity. They sought additional experiments to clarify such effects and controls to prevent them. According to the Commission, however, such requirements could be imposed only to prevent 'adverse effects', as narrowly defined then. On this basis, in 1997-98 the Commission granted commercial authorisation to some GM crops [37].

Greater public protest led to a a broader risk assessment. At the June 1999 meeting of the Environment Council, many member states declared that they would not consider further requests for commercial authorisation until new conditions were fulfilled. This *de facto* moratorium led the EU to revise the Deliberate Release Directive along more stringent lines. It now included long-term and indirect effects of GM crops, as well as effects of any changes in management practices, e.g. any switch to broad-spectrum herbicides.

In the late 1990s yet another risk issue arose: 'GM contamination'. Pollution discourses were popularised as a multiple metaphor, involving 'unnatural' genetic combinations, 'filthy lucre' perverting science, globalisation corrupting national sovereignty, as well as GM pollen

'contaminating' non-GM crops [38]. Friends of the Earth Europe adopted a honeybee logo to symbolize 'unwitting agents of genetic pollution', i.e. long-distance unmanageable spread of pollen. Initially this problem was framed in two different ways. According to the eco-efficiency frame of the agri-biotech industry, the unintentional presence of GM material is manageable through routine measures, thus protecting the economic value of non-GM crops. According to the apocalyptic frame, 'GM contamination' threatens the environment, consumer choice and even democratic decision-making.

In response to these discourses, new regulatory language reframed the segregation problem. The phrase 'adventitious presence' has denoted levels of GM material which remain technically unavoidable, despite the operator's reasonable efforts to minimise that presence; this phrase implies a moral obligation to exercise and demonstrate such efforts through segregation measures. As a more recent phrase, 'coexistence' expresses a policy aim to maintain farmer options through parallel systems for GM, conventional and organic crops.

In sum, critics kept agri-biotech on continuous trial through ominous risk metaphors, thus associating GM products with irresponsible or immoral behaviour. Eventually EU regulatory frameworks translated these metaphors into technical-managerial criteria for measuring and controlling more potential effects (see again Table 1). To manage the extra uncertainties, the authorities revised and re-interpreted the original legislation on agbiotech risk regulation.

3.3 Extending the stepwise procedure

From the start, EU agri-biotech regulation had adopted 'the step-by-step principle'. According to international guidelines, GMOs should be made predictable by progressively decreasing physical containment. Releases should follow 'a logical, incremental, step-wise process, whereby safety and performance data are collected' [39]. According to the Deliberate Release Directive, the scale of release is increased gradually, 'but only if the evaluation of the earlier steps... indicates that the next step can be taken', i.e. safely [40]. In so far as scientific uncertainty can justify a precautionary or proactive approach, it 'may be deemed necessary until a large and reassuring body of data has been accumulated and we can begin to treat the technology as familiar' [41].

Initially the step-wise principle was interpreted to mean that controls could be entirely relaxed at the commercial stage. Many expert advisors felt that risk assessment could not depend upon a particular manner of using a product, because such restrictions would be unfeasible at the commercial stage: 'If it needs special controls at that stage, then we have really lost it' [42]. For small-scale field trials in the mid-1990s, special measures confined the GM material, pending a regulatory decision on scale-up. From the empirical results, proponents cited 'no evidence of risk' as an argument for product safety, thus warranting no special conditions on product use.

However, special conditions were later imposed to address new agro-environmental issues. As described earlier, when the Directive was revised in the late 1990s, it required case-specific monitoring: 'the monitoring should confirm that any assumptions regarding the occurrence and impact of potential adverse effects of the GMO or its use in the environmental risk assessment (e.r.a.) are correct' [43]. Thus it extended the stepwise principle into the commercial stage.

Arguments continued over what 'assumptions' must be confirmed by monitoring commercial use, and whether some GM products would be exempt. On behalf of the European Commission, DG-Environment drafted guidelines which eventually allowed some exemptions from the monitoring requirements, as follows: 'Where the conclusions of the risk assessment identify an absence of risk or negligible risk, case-specific monitoring may not be required'

[44]. This exemption came from an eco-efficiency frame, e.g. from the agbiotech industry and from DG-Trade within the Commission.

The monitoring criteria became more contentious for specific GM products in 2003-2004, when European governments were once more deciding whether or how to support commercial approval of specific GM products. Under the Deliberate Release Directive, companies submitted each notification for a GM product to a national Competent Authority (CA). Then each member state could express views on the risk assessment and on appropriate requirements. They judged what extra control measures may be warranted. Initially those judgements remained unclear: 'Regulators have no clear criteria for what may or may not be considered an assumption for the purposes of requesting case-specific monitoring' [45]. The next section analyses EU-wide conflicts over such assumptions which need to be confirmed for specific GM products.

4 Disputing agbiotech experiments

In evaluating GM products for commercial approval from 2003 onwards, regulatory procedures considered ways to predict, test and/or prescribe the behaviour of agro-industrial operators who would handle the products. This section analyses regulatory conflicts over how to design commercial use as 'real-world experiments' – firstly for the generic issue of herbicide effects, and then for three specific products.

4.1 Broad-spectrum herbicides as a generic issue

GM herbicide-tolerant (GMHT) crops allow farmers to replace selective herbicides with broad-spectrum ones, whose potential benefits were disputed. From an eco-efficiency frame, GMHT crops help farmers to control weeds more efficiently, by delaying sprays until the post-emergence phase and/or reducing the quantities sprayed, thus benefiting the environment. According to UK nature conservation agencies, however, such efficiency could turn the countryside into 'green concrete'. Broad-spectrum herbicides could reproduce 'the sterility of the greenhouse in open fields', thus causing a drastic reduction in wildlife already depleted by modern agricultural practices [46]. Nearly two-thirds of UK land is agricultural, so critics asked whether broad-spectrum herbicides would cause more harm to biodiversity around fields, as compared to the selective herbicides previously used. Given that uncertainty, companies sought more evidence to justify commercial approval (see Table 1, penultimate row).

The UK government funded large-scale, on-farm trials over a four-year period. These Farm-Scale Evaluations (FSEs) aimed to test herbicide effects on farmland biodiversity. Through split-field trials, spraying GM herbicide-tolerant crops was compared to spraying their conventional counterparts. The experiments were intended to justify an eventual decision about approving herbicide-tolerant crops: 'The results of these farm-scale evaluations will ensure that the managed development of GM crops in the UK takes place safely' [47]. At the time, the FSEs gave the government a scientific rationale for postponing a politically awkward decision.

Elsewhere the FSEs have been analysed as a 'regulatory experiment', in the general sense that 'a policy needs to be put on trial, and an obvious regulatory purpose needs to be inscribed into the particular experimental design of the trial' – in this case, 'controlled conditions' for GM crops [48]. Indeed, the FSEs were designed to test a prospective policy: namely, permitting commercial use, while setting only a maximum limit on herbicide usage, though the timing could matter more than the quantity. To test such a policy, split fields provided an experimental 'control' or baseline for comparing biodiversity effects of the two different herbicide regimes.

In designing the trials, arguments arose over the appropriate comparators for GM crops. Those conflicts were accommodated by the experiment designers: 'to fully represent the range of potential biodiversity effects, a full range of current conventional practices used in the UK should be included in the research programme' [49]. Nature conservancy groups proposed that the design should include some conventional fields where farmers spray relatively less herbicides, to provide a more stringent comparator for broad-spectrum herbicides. Accepting that proposal, the designers included 'less intensive production systems' in the trial fields [50]. Nevertheless, government advisors signalled design weaknesses and wider issues that would still leave 'GM crops on trial' afterwards [51].

From the FSEs, preliminary results indicated large environmental differences between GM and non-GM crops. For two of the three crops, spring-sown oilseed rape and sugarbeet, much greater harm resulted from farmers spraying broad-spectrum herbicides, by comparison to spraying selective herbicides on their conventional counterparts. For example, the GM fields had fewer weed seeds and insects important for bird diets [52].

In response to those results, agri-biotech proponents argued that only the changes in herbicide use were 'on trial', not GM technology as such. From an eco-efficiency frame, any harm was caused by weed-management measures, which could be flexibly adjusted to benefit wildlife. According to a Bayer representative:

> Activist groups claim that GM crops were in effect 'green concrete' and would 'wipe out' wildlife. These studies show that this sort of scaremongering is not supported by the evidence [53].

In the case of the third crop tested, maize, relatively less harm resulted from spraying broad-spectrum herbicides than selective ones, e.g. atrazine. Since this herbicide was soon to be banned, NGOs criticised the comparison as invalid. They also questioned whether the experimental designs were realistic models for commercial practice, i.e. whether they really simulated farmers doing 'cost-effective weed control'.

In its eventual advice, the UK advisory committee accepted the results of the trials as valid only for their specific conditions. According to the government's advisory committee, adverse effects would not result 'if GMHT maize were to be grown and managed as in the FSEs'. Given that atrazine would be phased out soon, however, alternative herbicides could change the unfavourable comparison of conventional maize with GMHT maize, so there must be a scheme 'to monitor changes in conventional management practice'. For GMHT spring-sown oilseed rape, the expert body would not support commercial approval, unless companies submitted proposals and evidence for how the glufosinate sprays could be managed to minimise harm [54].

4.2 Maize cultivation

Farmland biodiversity issues became more specific for Bayer's herbicide-tolerant T25 maize, which had already gained EU authorisation in 1998. Each member state could set its own terms for cultivation, especially regarding herbicide usage (see Table 2, first product). Citing the FSE evidence of environmental benefits, the UK government ultimately announced that it would approve the crop for the 2005 season, but with extra conditions: First, herbicide spraying must follow the herbicide practices used in the FSEs or other practices 'that have been shown not to result in adverse effects'. Second, after 2006 further trials would be necessary to redo the environmental comparison with whatever herbicides replace atrazine. Moreover, for any non-GM farmer whose crop loses economic value as a result of gene flow, there would be a compensation scheme 'to be funded by the GM sector' [55].

[insert Table 2]

In those ways, commercial cultivation was anticipated and designed as a semi-controlled experiment on farmer practices. The FSEs were originally intended to simulate farmer

behaviour and thus to predict environmental effects, as a realistic basis for relaxing control measures. Instead expert advice now cited the empirical results to prescribe farmer practices, which themselves would need monitoring for compliance. Thus the commercial stage was made conditional upon real-world experiments to test farmer practices regarding the two risk issues – farmland biodiversity and admixtures from gene flow. For segregation measures to avoid admixture, a compensation fund would give companies a financial incentive to enforce and monitor farmers' compliance with guidelines.

Having obtained a conditional go-ahead, Bayer Crop Science applauded the UK announcement – but withdrew its application. According to the company:

> The Government has however placed a number of constraints on this conditional approval before the commercial cultivation of GM forage maize can proceed in the UK. The specific details of these conditions are still not available and thus will result in yet another 'open-ended' period of delay. These uncertainties and undefined timelines will make this five-year old variety economically non-viable [56].
>
> New regulations should enable GM crops to be grown – not disable future attempts to grow them [57].

The company declined to take responsibility for a commercial-scale experiment in a 'economically non-viable' context. Rules would impose extra burdens, e.g. post-market monitoring and financial liabilities of co-existence measures, yet this five-year-old variety would give farmers no clear benefits relative to other options [58]. In particular, T25 maize used an inferior germplasm, relative to other varieties more recently available.

Moreover, regulators found difficulties in requiring a semi-controlled experiment at the commercial stage. According to UK legal advice, the Directive provided no clear basis for a member state to require a specific herbicide regime, so the authorities withdrew their original proposal. For various reasons, then, regulatory approval would depend upon predicting realistic effects – rather than prescribing or prohibiting their behavioural causes.

4.3 Oilseed rape cultivation

Under the revised Directive, Bayer Crop Science sought commercial authorisation for a herbicide-tolerant oilseed rape which had been delayed by the 1999 EU Council moratorium. Within its new application, the company included cultivation guidelines for growers. Although not required *a priori*, these guidelines would have statutory force, thus incorporating aspects of a managerialist frame into an experimental design. Yet the company's plan was criticised for optimistic assumptions.

- Efficient weed control versus biodiversity?

In its risk assessment, Bayer translated the 'superweed' scenario into managerialist terms. According to its guidance, farmers would efficiently use herbicides to keep fields clean of weeds. They planned multi-year field tests to evaluate weed-control methods, as well as any potential unexpected effects of this crop. For the prospect of generating herbicide-tolerant weeds, the overall risk was assessed as nil, 'taking into account the risk management strategies' [59].

Emphasising product efficiency, Bayer claimed that its stewardship programme would provide 'cohesive guidelines for field management' by farmers. 'Different networks of expertise are being consolidated in all countries by testing the efficiency of the herbicide and the performance of the varieties'. According to the results available so far, 'Standard Good Agricultural Practices provide adequate control of transgenic oilseed rape volunteers', i.e. seeds which germinate after harvest [60].

Thus the company proposed to manage herbicide-tolerant weeds as if they could be an adverse effect. The case-specific monitoring plan was designed to confirm the company's assumptions about the occurrence, impact and management of such weeds in particular. The

monitoring would compare matched pairs of GM and non-GM oilseed rape fields. The plan aimed to demonstrate that 'the potential adverse effects identified in small-scale field trials (volunteers and outcrossing) are fully manageable in a practical way in farmers' fields' [61]. Bayer would licence the herbicide-tolerance system to seed companies, rather than own and market the seed directly, thus complicating the locus of responsibility: 'This means that stewardship becomes more difficult, requiring shared responsibility among stakeholders' [62].

Moralising the environment in its own way, the company also undertook to share responsibility with farmers, who faced a cultural conflict between efficient weed control and farmland biodiversity. Consequently, a company manager foresaw the need for 'cultural teaching':

> … where the farmer can adapt the [spraying] practice according to the real weed infestation (due to post-emergence application), it is possible to overcome this conflict…
> For example, we could leave part of each field unsprayed, which would provide an environmental benefit. We needn't kill all the weeds. Instead we can apply the herbicide only when and where necessary during the season. But it is not farmers' culture to leave weeds growing in the field. So we will need to do cultural teaching about the moral obligation of farmers to know the environmental consequences of their actions [63].

- Belgian rejection

For Bayer's marketing application to cultivate herbicide-tolerant oilseed rape, regulators considered all three risk issues from the public debate (see again Table 1, lower half; and Table 2, second product). As rapporteur for the EU-wide procedure, the Belgium CA sought the views of its own advisors. They emphasised the problem that oilseed rape can readily become a weed, as well as spreading its genes through pollen flow to other *Brassica* plants. For preventing this gene flow, the company's guidelines would be essential, but they are 'not all technically feasible', so vertical gene flow 'may not be controlled', argued advisors. Therefore post-market monitoring must assess farmer compliance with the guidelines. The advice also mentioned two other problems: adventitious presence of GM material, with problems for coexistence; and broad-spectrum herbicides allowing better weed control and thus 'cleaner' fields, i.e. less biodiversity in farmland [64].

Indeed, farmland biodiversity became a new regulatory issue through this case. Belgian advisors initially accepted the company argument that the issue lay within regulation of pesticides, not GM crops. However, Belgian anti-biotech campaigners circulated copies of the UK FSE results to the advisory body and held protest actions [65]. Ultimately Belgian experts reiterated the UK conclusion that 'cost-effective weed control' would result in adverse effects on farmland biodiversity, at least in the short term. Therefore the problem requires 'a continued monitoring of continuously evolving agricultural practices'. Indeed, such an effort would be worthwhile for all pesticide usage, since it could have anticipated the decay of farmland biodiversity in recent decades, argued Belgian advisors [66].

Citing that advice, the Belgian government decided to reject cultivation uses of the Bayer crop. Its official rationale mentioned all three risk issues: herbicide-tolerant weeds, farmland biodiversity and admixture [67]. According to the Environment Minister, the broad-spectrum herbicide 'kills food for birds, bees and everything else that lives in nature', thus reclassifying farmland as nature [68]. Such apocalyptic language supported a decision that would avoid domestic and EU-wide conflict.

The Belgian advisory body had implied the need to impose and monitor extra control measures on crop cultivation, but the government declined to attempt such an experiment. Instead it advocated approval only for grain import, not cultivation. In response, Bayer criticised the government decision as political: 'The experts raised some concerns but indicated that with proper controls it would be possible to cultivate this crop without impacting on the environment', according to the company [69]. On the other side, Belgian

NGOs opposed even grain import, by arguing that the government should not encourage cultivation of such crops anywhere, 'in view of their uncontrollable environmental and agricultural consequences' [70].

4.4 Rapeseed import

For grain import only of GM products, companies expected the environmental risk assessment to be straightforward, warranting no special requirements. 'The grain handling system excludes grain from the environment', according to a company regulatory manager (interview, April 2003). For such products from Monsanto, the company claimed that any risk would be 'effectively zero'.

However, a proposal to import GM rapeseed provoked great conflict, partly about the weediness scenario (see Table 2, third product). The company's risk assessment made optimistic assumptions – e.g., that environmental release from grain imports can be prevented or managed, and that any escaped seeds that germinate would be readily displaced by other weeds. Environmental NGOs criticised those assumptions. Moreover, they argued, it would be unacceptable to spray extra herbicides on roadsides to control volunteers, and GM crops should be prohibited in centres of biodiversity for *Brassica* species [71].

National experts and regulators anticipated that some grain could escape. Italy objected that any escaped rapeseed could contaminate related plants, especially land races, and thus undermine its national centres of diversity for *Brassica* crops. The UK advisory committee, concerned about 'the segregation of transgenic and non-transgenic material', asked that the company 'include plans for monitoring and controlling establishment of feral populations as a result of seed spill' [72]. Expert advisors were asking the company to test nearby populations for the herbicide-tolerance trait, as a means to confirm its optimistic assumptions.

Taking up those issues, governments proposed extra conditions that would test and even prescribe importers' behaviour. According to the UK, any EU authorisation should include 'acceptable procedures to minimise seed spills' and 'active monitoring', especially to confirm that populations of feral herbicide-tolerant oilseed rape do not emerge [73]. Likewise Danish experts proposed that EU approval should include control measures to prevent unintended dispersal during grain transport at harbours, as well as monitoring of any dispersal and gene transfer [74].

Regulators disagreed about whether or how to impose such conditions – implicitly, about whether GM rapeseed import must be specially designed as a real-world experiment. According to the company, it could not feasibly take responsibility for extra control measures at ports or processing plants, which lay beyond its own authority. Eventually the European Commission proposed to authorise the GM rapeseed import without such a requirement, thus accepting the company's minimal plan as adequate [75]. When that proposal went for a vote to the regulatory committee in June 2004, more member states voted against approval than in favour [76].

When the Commission ultimately granted approval a year later, this potentially held the company responsible for designing and monitoring commercial use as an experiment. The official decision required 'appropriate management measures to be taken in the case of accidental grain spillage'. The Commission also announced a 'Recommendation concerning measures to be taken by the consent holder to prevent any damage to health and the environment' from accidental spillage [77].

5 GM crops kept on trial

Like previous agricultural technologies, agbiotech has been turned into a legitimacy problem for government decision-making in Europe. A metaphor of suspected crimes, 'GM crops on trial', has been extended into public debate and EU-wide regulatory procedures. GM crops have been kept continuously on trial in three related ways: contending risk discourses which attribute moral meanings to the agricultural environment, safety tests which simulate commercial use, and special measures which assign greater responsibility to commercial operators. All these elements intersect in regulatory conflicts over how to anticipate and design commercial use as a real-world experiment. This section summarises how the analysis has drawn upon the theoretical perspectives surveyed earlier.

5.1 Contending agri-environmental discourses

The agri-biotech debate features contending moral frames about GM products conserving or degrading nature, as in many other agri-technological controversies [78]. Proponents and opponents have framed GM crops according to different moral visions of the socio-natural order (see Diagram 1, upper left corner; and Table 1, upper half). From their eco-efficiency frame, proponents have diagnosed the problem as agro-economic inefficiencies which GM crops can remedy; they have framed any unintended effects as routinely manageable problems of safe products. By contrast, agri-biotech opponents have emphasised apocalyptic threats – e.g., of uncontrollable risks, intensive agricultural methods and farmer dependence on multinational companies. They have counterposed benign alternatives, especially farm stewardship roles which have cultural resonances in each country – for example, farmland biodiversity in the UK, local specialty products in Italy, peasant craft skills in France, etc. In these ways, eco-efficiency versus apocalyptic frames favour different future scenarios for linking nature, society and technology [79].

Apocalyptic risk discourses have blurred official distinctions between environmental, agricultural and economic harm. In recent decades, intensive cultivation methods had eroded any distinction between society and agricultural nature, whose injuries became more open to socio-cultural definitions, amenable to stigmatising agbiotech. Risk metaphors have anticipated potential harm in ways which resonated with public concerns, e.g. about unaccountable economic forces imposing an irreversible future. As culturally-believable diagnoses of societal problems, these risk discourses provided a collective action-frame for mobilising public support and pressurising governments [80].

Moreover, agbiotech opponents have framed risk in successively broader ways, thus expanding the charge-sheet of suspected crimes for which GM crops should be kept on trial. Their discourses have emphasised three ominous metaphors: 'superweeds' leading to a genetic treadmill, thus aggravating the familiar pesticide treadmill; broad-spectrum herbicides 'sterilising' farmland biodiversity; and pollen flow 'contaminating' non-GM crops. They have also cast doubt on whether preventive measures would be reliable, realistic or morally responsible. In these ways, they have sought to undermine safety claims; indeed, they have cast the entire technological development as immoral, thus challenging eco-efficiency discourses of societal benefits (see Table 1, lower half).

Through a managerialist frame, governments have mediated between eco-efficiency and apocalyptic frames, especially by translating the three ominous metaphors into measurable, manageable effects. By treating 'contamination' as 'adventitious presence', for example, they scientised the risks and thus the protest [81]. More national authorities took up those risk issues, which readily became European ones through interactions between activists and regulators. Governments defined harm more stringently, thus generating more uncertainty about whether GM crops could cause harm. Indeed, fact-finding for risk knowledge became dependent upon value-laden accounts of harm, especially pollution [82].

5.2 Real-world experiments

Regulatory science conventionally identifies testable characteristics of a product within standard contexts of its use, as a basis to distinguish between knowledge which is necessary or merely 'nice to know' [83]. For GM crops the 'step-wise procedure' was originally meant to provide the knowledge necessary to relax control measures for 'safe products' at the commercial stage. As critics warned against 'uncontrollable risks' of GM products, however, a managerialist frame evaluated a broader range of potential harm than before. The 'step-wise procedure' was extended into proposals for the commercial stage.

Regulators requested more knowledge about operator behaviour and diverse agri-environmental conditions – contexts which could not be standardised in advance. Risk assessments increasingly made assumptions or prescriptions about the operator behaviour necessary to avoid harm. Control measures assigned greater legal-moral responsibility to agro-industrial operators, including seed companies, grain importers, farmers, etc. (Diagram 1, lower middle part).

The original policy problem, evaluating 'product safety', was reconstructed by keeping GM crops on trial in the experimental sense. Although the Commission policy was 'science-based regulatory oversight', new practices extended the disciplinary boundaries of science. The commercialisation stage was now anticipated and designed as a real-world experiment. Such designs would test assumptions about human practices as well as their environmental effects [84]. These steps towards commercialisation could be justified as cautious ways to generate knowledge for risk assessment, thus providing moral licence for a technological scale-up (Diagram 1, upper right-hand corner).

The agri-production chain was being effectively turned into a social laboratory for operator behaviour. Farmer discipline was needed to control weeds, or to protect some weeds as biodiversity, or to do both at once – aims which may be mutually conflicting. As farmers were assigned a role as environmental stewards, their potential behaviour became a focus for greater monitoring, control and self-discipline. For cultivating the most controversial GM crop (oilseed rape), a company planned moral education for farmers, so that herbicide sprays would minimise harm to farmland biodiversity. For the import of GM rapeseed, some member states now sought extra measures to limit and monitor any spillage, which could lead to harmful herbicide sprays.

Conflicts arose about whether operator behaviour could be feasibly reorganised around the necessary social discipline to prevent harm, and thus about how to design a technological scale-up (see again Table 2) [85]. For the prospect that gene flow would generate herbicide-tolerant weeds, a biotech company devised control measures for farmers to maintain 'clean' weed-free fields, but expert advisors questioned whether such measures were feasible. For the prospect that broad-spectrum herbicides would harm farmland biodiversity, farm-scale trials were originally intended to simulate cultivation practices and thus predict their environmental effects, as a basis to make a regulatory decision on commercial use. However, those cultivation practices were later made prescriptive, as rules to be enforced and monitored for compliance. For the prospect that GM crops would 'contaminate' non-GM crops, national measures assigned legal responsibility and liability to companies, thus involving them in farmer discipline. All these potential control measures became contentious in European regulatory procedures during 2004.

Those procedures have undergone tensions between predicting, testing and prescribing operator behaviour. Conflicts arose over the necessity or feasibility of control measures which would extend operator responsibility through real-world experiments. By generating these regulatory conflicts, the apocalyptic frame somewhat achieved its aim: to impede or deter further commercialisation of GM products.

6 Links among theoretical perspectives

This case study has given complementary roles to three theoretical perspectives: issue-framing, agri-environmental discourses, and real-world experiments. This final section elaborates how the case study links and develops those perspectives, especially for their policy implications (see again the boxes in Diagram 1).

Other case studies have analysed agri-environmental discourses as contending moral visions for agri-technological change. In particular, agrochemicals and bovine growth hormone were attacked as techno-fixes which evade or even aggravate the sources of socio-environmental problems. Farmers' roles as environmental stewards became a focus for 'moralising the environment', by attributing moral meanings to their behaviour and its environmental effects [86].

Building upon those perspectives, this case study links environmental discourses with issue-framing, by analysing interactions among three frames [87]. Amidst two frames promoting or opposing agbiotech, regulatory authorities elaborated a distinct managerialist frame, incorporating and synthesising elements of the other two. New managerialist procedures scientised the ominous metaphors through efforts to control 'uncontrollable risks', while mediating between the antagonistic frames, though without a clear outcome for commercialising the products.

In science and technology studies, other case studies have analysed how technological development is designed and managed as a real-world experiment – e.g. by extending, testing and adjusting control measures at the commercial stage. In some sectors, e.g. household or toxic waste disposal, the experimental design has been socially negotiated in ways which could manage or reduce social conflict. Wider deliberative participation through real-world experiments can help legitimise decisions [88].

In this case study, however, opponents stigmatised agri-biotech as pollution, turning the entire development into a Europe-wide legitimacy problem. The managerialist frame broadened the policy problem by experimentalising the commercial stage, yet its design became contentious. These difficulties are illuminated by linking perspectives on agri-environmental discourses and real-world experiments.

What broader lessons can be drawn from this case? According to Hajer, an environmental discourse can be appropriated for various agendas – for example, by protest movements for blocking a development, or by political elites for taking responsibility for a common societal problem. He further distinguishes between two managerial approaches: 'environmental mediation' and 'reflexive institutional arrangements'. Through environmental mediation, an elite group deliberates possible solutions to environmental problems: this procedure may need to delimit the problem-definition in order to reach internal consensus. By contrast, through reflexive institutional arrangements, a broader social process would reconsider the basis of environmental knowledge and 'can therefore never be based on preconceived problem definitions'. Reflexive practices should 'be oriented towards constructing the social problem' that needs a solution in socially inclusive ways. These would discuss diverse possibilities for social order, e.g. in terms of 'what constitutes pollution' [89].

Juxtaposed with Hajer's two managerial models, this case study mainly illustrates environmental mediation, though with some reflexive elements. For agbiotech a managerialist frame reflexively broadened the original policy problem – from assessing product safety, to designing real-world experiments. Political elites could take responsibility for a new common problem: keeping GM products on trial, while judging whether a particular experiment was acceptable. EU agbiotech regulation can be seen as predominantly an elite project: environmental mediation tested social assumptions about human practices and their

potential effects. Through greater reflexivity, regulatory procedures incorporated more conflicts – over operator self-discipline, appropriate control measures, and diverse accounts of pollution.

According to Commission policy, EU 'science-based regulatory oversight' is the basis for 'societal choices' regarding agbiotech. This role poses a fundamental difficulty – raising the political stakes for regulatory decisions, but allowing little scope to deliberate visions of the socio-natural order. Real-world experiments can help to manage legitimacy problems but not to overcome them. This tension indicates both the reflexive potential and limitations of a policy framework which regulates biophysical 'risk' of a contentious innovation.

TABLES

Table 1: Three Contending Risk-Frames for GM Crops

	Eco-efficiency/cornucopian agri-biotech business, e.g. Europabio, some farmers	**Managerialist** regulatory agencies, e.g. DG-Environment & national regulatory agencies	**Apocalyptic** environmental NGOs, *Coordination Paysanne*, Green MEPs
Agricultural problem	inefficient farm inputs, uncompetitive outputs	uncertain biophysical effects of a new technology	intensive monoculture, farmer dependence on MNCs, pesticide treadmill
Nature seen as	cornucopian potential to be reaped	resources to be managed and protected	fragile resources under threat from uncontrollable, irreversible risks
GM crops seen as	safe eco-efficient tools to gain economic & environmental benefits	potential hazards to be evaluated and managed	pollutants threatening the environment, democracy and societal values
Solution	apply routine management measures	design research and controls to manage uncertainty	block or deter GM products
1) herbicide-tolerant weeds	manage this agronomic problem through product stewardship, e.g. standard Good Agricultural Practices (GAP)	evaluate control measures and their feasibility for this agro-environmental problem (which could affect herbicide usage)	prevent 'genetic treadmill' & 'superweeds' which would perpetuate agrochemical dependence
2) harm to farmland biodiversity from 'total' herbicides	use herbicides more efficiently and so reduce environmental harm Bayer: plan moral teaching for farmers.	test relative harm of broad-spectrum and selective herbicides – effects contingent upon farmer practices	prevent herbicides from sterilising the countryside into green concrete
3) mixture of GM and non-GM crops	protect non-GM crops through standard isolation distances (for each crop)	limit adventitious presence through national measures for segregation and co-existence	prevent 'genetic contamination' – but impossible or difficult

Abbreviations
GAP: Good Agricultural Practices
MEP: Member of the European Parliament
MNC: multinational companies
NGO: non-governmental organisation

Table 2: Managerialist Risk-Frames as Experimental Designs

Note: National Competent Authorities (CAs) and their expert advisory bodies have attempted to impose extra conditions upon GM products under the Deliberate Release Directive. The managerialist risk-frame (in Table 1) was operationalised by designing commercial use as an experiment. This table summarises conflicts over specific herbicide-tolerant (H-T) crops, regarding the three risk issues.

	Bayer's herbicide-tolerant maize for cultivation	**Bayer's herbicide-tolerant oilseed rape (OSR) for cultivation**	**Monsanto's herbicide-tolerant OSR for import only**
Regulatory proposals and decisions	EU-wide approval already granted in 1998, but each country can restrict herbicide usage. UK proposed approval with extra conditions in March 2004, but Bayer withdrew application	Belgium decided not to support EU approval for cultivation in February 2004.	CAs demanded special conditions to monitor and control escape of grain. Commission decision partly accommodated those demands
Risk issues			
1) herbicide-tolerant weeds: evaluate control measures and their feasibility for this agro-environmental problem	(not a major issue for maize)	Bayer planned product stewardship for farmers to eliminate volunteer weeds for 'clean' fields. Belgian advisers doubted feasibility of Bayer's plan.	UK proposed preventive measures and 'active monitoring' of feral populations, to verify the company reassurances about seed containment.
2) farmland biodiversity: test relative effects of total (broad-spectrum) and selective herbicides through Farm-Scale Evaluations (FSE)	FSEs showed relatively less harm from GM maize. UK advisers supported authorisation only if farmers use herbicides as in the FSEs. Regulators adopted that advice for their decision.	FSEs showed relatively greater harm from GM OSR. UK advisers did not support authorisation. Belgian advisers noted the unfavourable results of UK FSEs.	NGOs argued that it would be unacceptable to spray total herbicides on roadside areas. To avoid any need for sprays, UK advisers sought to prevent spillage.
3) mixture of GM and non-GM products: limit adventitious presence through co-existence measures set at national level	UK would require companies to fund any compensation to non-GM farms whose crops lose economic value.	Belgian advisers noted the segregation problem.	UK advisers expressed concern about segregation. But Monsanto defended routine procedures as adequate.

Acknowledgements and methods

This paper arises from a research project, 'Precautionary Expertise for GM Crops' (PEG), funded by the European Commission, Quality of Life programme, socio-economic aspects, during 2002-2004 (contract no. QLG7-2001-00034). In that project, documents were analysed as a basis to formulate research questions for semi-structured interviews. Interview quotes come from transcripts or from notes checked by the interviewee. The overall interview material influenced the analysis and selection of documentary detail included here.

In drafting this paper, helpful comments were received from members of the PEG research team (Christophe Bonneuil, Karin Boschert, Sue Oreszczyn, Piet Schenkelaars, David Wield) and from other readers (Seife Ayele, Sébastien Denys, Les Firbank, Frank Fischer, Beth Greenhaugh, Farah Huzair, Javier Lezaun, Peter Robbins, Bronislaw Szerszynski, Rene von Schomberg, Johannes Weyer and anonymous readers of this journal).

References

[1] Y.Surel, The role of cognitive and normative frames in policy-making, *Journal of European Public Policy*, 7 (2000): 495-512.

[2] R.D. Benford and D.A. Snow, Framing processes and social movements: an overview and assessment, *Annual Review of Sociology* 26 (2000): 611-639.

[3] J.R. Clark and A. Jones, Agricultural elites, agrarian beliefs and their impact on the evolution of agri-environmental policies, *Environment and Planning A* 30 (1998): 2227-43.

[4] P.Lowe, N.Ward, S.Seymour, J.Clark, 'Farm pollution as environmental crime', *Science as Culture* 5 (1996): 588-612.

[5] P.Lowe, J.Clark, S.Seymour, N.Ward, *Moralising the Environment: Countryside Change, Farming and Pollution*, London: UCL Press, 1997.

[6] N.Ward, J.Clark, P.Lowe, S.Seymour, Keeping matter in its place: pollution regulation and the reconfiguring of farmers and pollution, *Environment and Planning A* 30 (1998): 1165-1178.

[7] F.H. Buttel, Nature's place in the technological transformation of agriculture: some reflections on the recombinant BST controversy in the USA, *Environment and Planning A* 30 (1998): 1151-63.

[8] P.Macnaghten and J.Urry, J., Towards a sociology of nature, *Sociology* 29 (1995): 203-20, at pp.211-12.

[9] U.Beck, *Risk Society: Towards a New Modernity*. London: Sage, 1992, p.81.

[10] Ibid., pp.155-161.

[11] S. Funtowicz and J.Ravetz, Science for the post-normal age, *Futures* 25 (1993): 735-55, at pp.750-51.

[12] M.Hajer, *The Politics of Environmental Discourse: Ecological Modernisation and the Policy Process*, Oxford: Oxford University Press, 1995, pp.55-56.

[13] Ibid.

[14] M.Schwarz and M.Thompson, *Divided We Stand: Redefining Politics, Technology and Social Choice*, London: Harvester, 1990.

[15] S.M. Macgill and Y.L. Siu, A new paradigm for risk analysis, *Futures* 37 (2005): 1105-31, at pp.1127-28.

[16] A. Irwin, H. Rothstein, S. Yearley, E. McCarthy, Regulatory science – towards a sociological framework, *Futures* 29 (1997): 17-31, at p.25.

[17] W. Krohn and J.Weyer, Society as a laboratory: the social risks of experimental research, *Science and Public Policy* 21(3) (1994): 173-183.

[18] Ibid, p.174.

[19] Ibid, pp.174-76.

[20] Ibid, p.181.

[21] R. Herbold, Technologies as social experiments: the construction and implementation of a high-tech waste disposal site, in A. Rip et al., eds, *Managing Technology in Society: The Approach of Constructive Technology Assessment*, London: Pinter, pp.185-95, at p.193.

[22] W.Krohn, Waste Sites as Experiments: Producing Knowledge about Waste, 2002, p.25, http://www.uni-bielefeld.de/iwt/realworld/

[23] M. Gross and W. Krohn, Science in a real-world context: constructing knowledge through recursive learning, *Philosophy Today* 48(5) (2004): 38-50, at p.48.

[24] B. Wynne, Technology Assessment and reflexive social learning: observations from the risk field, in A. Rip et al., eds, *Managing Technology in Society: The Approach of Constructive Technology Assessment*, 1995, pp.19-36, at p.25, London: Pinter.

[25] Ibid, p.31.

[26] EuropaBio, Environment Ministers pave way for Council common position on GM, December 2002, http://www.europabio.org/pages/index.asp

[27] Ibid.

[28] *Biotechnology: A Plain Man's Guide to the Support and Regulations in the UK*, Cambridge: Laboratory of the Government Chemist, UK Department of Trade & Industry, 1991.

[29] B. Haerlin, Genetic engineering in Europe, in P.Wheale and R.McNally, eds, *The Bio-Revolution: Cornucopia or Pandora's Box?*, 1990, London: Pluto Press, pp. 253-61.

[30] GenetiX Snowball brochure, 1998, http://www.gn.apc.org/pmhp/gs

[31] To change the CAP, Brussels: Coordination Paysanne Européenne, 2001, www.cpefarmers.org

[32] 17 April 2002: International Day of Farmers Struggles against GMOs, Brussels: Coordination Paysanne Européen, 2002, www.cpefarmers.org

[33] C. Heller, From scientific risk to *paysan savoir-faire*: peasant expertise in the French and global debate over GM crops, *Science as Culture* 11(1) (2002): 5-37.

[34] Commission of the European Communities, Towards a Strategic Vision of Biotechnology and Life Sciences: Progress Report and Future Orientations, 5 March 2003, p.17.

[35] Life Sciences and Biotechnology: a Strategic Vision for Europe, COM(2002) 27 final, Communication from the Commission to the Council, the European Parliament, the Economic and Social Committee and the Committee of the Regions, 2002, p.14, http://europa.eu.int/comm/biotechnology/introduction_en.html

[36] Council Directive 90/220 on the Deliberate Release to the Environment of Genetically Modified Organisms, *Official Journal of the European Communities*, L 117 (8 May 1990): 15-27.

[37] L. Levidow and S. Carr, eds, Precautionary Regulation: GM Crops in the European Union, special issue of the *Journal of Risk Research* 3(3) (2000): 187-285.

[38] L. Levidow, Pollution metaphors in the UK biotechnology controversy, *Science as Culture* 9 (2000): 325-51.

[39] OECD, *Recombinant DNA Safety Considerations*, Paris: OECD, 1986, p.29.

[40] Op.cit., n36, p.l5.

[41] J. Tait and L. Levidow, Proactive and reactive approaches to risk regulation: the case of biotechnology, *Futures* 24 (1992): 219-31, at p.223.

[42] Interview, member of the Advisory Committee on Releases to the Environment (ACRE), UK, 1991.

[43] European Parliament and Council Directive 2001/18/EC of 12 March on the deliberate release into the environment of genetically modified organisms and repealing Council Directive 90/220/EEC, *Official Journal of the European Communities* L 106 (17 April 2001): 1-38, Annex VII.

[44] Commission Decision of 3 October establishing guidance notes supplementing Annex VII to European Parliament and Council Directive 2001/18/EC on the deliberate release into the environment of genetically modified organisms and repealing Council Directive 90/220/EEC, *O.J.* L 280 (18 October 2002): 27-36, p.31.

[45] Interview, company regulatory manager, April 2003.

[46] The spiralling agenda of agricultural biotechnology, *ENDS Report* 283 (1998): 18-30.

[47] Dept of the Environment, Transport and the Regions (DETR), Farm-scale evaluations of the impact of the management of GM herbicide tolerant oil-seed rape and maize on farmland wildlife, 1999, http://www.environment.detr.gov.uk/acre/wildlife/index/htm

[48] J. Lezaun and Y. Millo, Regulatory experiments: GM crops and financial derivatives on trial, *Science and Public Policy* 33(2) (2006): 179-90.

[49] GM Crop Farm-Scale Evaluations, minutes of the Scientific Steering Committee, 14 June 1999, http://www.environment.detr.gov.uk/fse/steering/jun14.htm

[50] GM Crop Farm-Scale Evaluations, minutes of the Scientific Steering Committee, 10 March 2000, http://www.environment.detr.gov.uk/fse/steering/00mar10.htm

[51] Agricultural and Environment Biotechnology Commission, *Crops on Trial*, 2001, www.aebc.gov.uk

[52] Dept of the Environment, Farming and Rural Affairs (DEFRA), GM Crops: Effects on Farmland Wildlife, 2003, http://www.defra.gov.uk/environment/gm/fse/results/fse-summary.pdf; Scientific Steering Committee for the GM crop farm-scale evaluations: final advice to Ministers, 2003, http://www.defra.gov.uk/environment/gm/fse/results/ssc-advice.htm

[53] Sound science has its say on GM crops and biodiversity, *ENDS Report* 345 (2003): 27-31, at p.31.

[54] Advisory Committee on Releases to the Environment (ACRE), Advice on Implications of the Farm-Scale Evaluations of GM Herbicide-Tolerant Crops, 2004, pp.10, 13, http://www.defra.gov.uk/environment/acre

[55] Statement on GM policy by Secretary of State Margaret Beckett, 9 March 2004, http://www.defra.gov.uk/corporate/ministers/statements/mb040309.htm; Limited go-ahead for GM crops, *ENDS Report* 348 (2004): 12.

[56] Bayer Crop Science discontinues further efforts to commercialise GM forage maize in the UK, 31 March 2004, www.bayercropscience.com

[57] P. Hennessy, GM firm pulls out of scheme to grow maize, *Evening Standard*, 31 March 2004: 18; J. Vidal, Firm drops plan to grow GM maize, 1 April 2004, www.guardian.co.uk/gm

[58] Interview, Bayer regulatory manager, May 2005.

[59] Bayer Crop Science, Full notification C/BE/96/01 for oilseed rape Ms8xRf3, including Environmental Risk Assessment & Post-Marketing Monitoring Plan, December 2002.

[60] Ibid.

[61] Bayer Crop Science, SNIFs for glufosinate-tolerant oilseed rape Ms8xRf3, http://gmoinfo.jrc.it/csnifs/C-BE-96-01.pdf, and for glufosinate-tolerant oilseed rape Liberator, 2003, pHoe6/Ac, http://gmoinfo.jrc.it/csnifs/C-DE-98-6.pdf

[62] Interview, Bayer regulatory manager, April 2003.

[63] Interview, Bayer regulatory manager, April 2003.

[64] Advice of the Biosafety Advisory Council on the notification C/BE/96/01 (transgenic oilseed rape - Bayer CropScience) under Article 35 of Directive 2001/18/EC, 26 Jan. 2004, http://www.biosafety-council.be/docs/BAC_2004_SC_084.pdf

[65] S. Denys, Engager les OGM dans une innovation démocratique et scientifique, typescript, Bruxelles: ULB, 2005, sdenys@ulb.ac.be

[66] Advice of the Biosafety Advisory Council on the British report "On the rationale and interpretation of the Farm-Scale Evaluation (FSE) of genetically modified herbicide-tolerant crops", Brussels, 26 Jan. 2004, http://www.biosafety-council.be/docs/BAC_2004_SC_087.pdf

[67] Assessment report in accordance with Directive 2001/18/EC: notification C/BE/96/01 oilseed rape, Federal Publique Service of Public Health, Food Chain Safety and Environment, Brussels, 26 Jan. 2004, http://www.biosafety.be/TP/partC/StatementBE_C_BE_96_01.pdf

[68] Reuters bulletin, 2 February 2004

[69] J. Vidal, Belgian authorities accused of making political decision on GM rape, *The Guardian*, 3 Feb 2004.

[70] S. Detaille, Pas dans les champs, pas encore dans l'assiette, *Le Soir*, Brussels, 3 fevrier 2004.

[71] Friends of the Earth Europe (FoEE), Comments on Part C product file, Monsanto RR oilseed rape, event GT73 (C/NL/98/11), 2003.

[72] Advisory Committee on Releases to the Environment (ACRE), Advice on notification C/NL/98/11, oilseed rape genetically modified for tolerance to glyphosate herbicides, line GT73, 10 March 2003, p.6, http://www.defra.gov.uk/environment/acre/advice/advice23.htm

[73] DEFRA, UK responses to marketing notifications under the Deliberate Release Directive, 2003, http://www.defra.gov.uk/environment/gm/regulation/euconsent.htm

[74] Danish Forestry and Nature Agency, letters to DG Environment, 24 March and 30 September 2003.

[75] Draft Commission Decision on oilseed rape GT73 line, 2004.

[76] New EU member states block Monsanto – twice, *FoEE Biotech Mailout,* July 2004.

[77] Commission Decision of 31 August 2005 concerning the placing on the market, in accordance with Directive 2001/18/EC of the European Parliament and of the Council, of an oilseed rape product (*Brassica napus* L., GT73 line) genetically modified for tolerance to the herbicide glyphosate, *O.J.* L228 (3 September 2005): 11-13. Commission authorises import of GM oilseed rape for use in animal feed, Press Release, 31 August 2005.

[78] Compare with op. cit. notes 4-7.

[79] Compare with Hajer, op. cit. note 12.

[80] Compare with Benford and Snow, op. cit. note 2.

[81] Compare with Beck, op. cit. note 10.

[82] Compare with Funtowicz and Ravetz, op. cit. note 11.

[83] Compare with Beck, op. cit. note 16.

[84] Compare with Krohn and Weyer, op. cit. note 17.

[85] Compare with Wynne, op. cit. note 24.

[86] Compare with op. cit. notes 4-7.

[87] Op. cit. notes 2, 12, 14.

[88] Op. cit. notes 21-24.

[89] Op. cit. Hajer, note 12, pp.80-84, 285-87, 281-2.