# Institutions and GMOs: Shaping Perspectives and Organisms

Institusjoner og GMOer: Forming av perspektiver og organismer

Philosophiae Doctor (PhD) Thesis

Valborg Kvakkestad

Dept. of Economics and Resource management
Norwegian University of Life Sciences

Ås 2010

Thesis number 2010:35
ISSN 1503-1667
ISBN 978-82-575-0945-3

**Abstract**

This thesis is written within the contemporary classical institutional economics tradition. The intention has been to provide insight into how different institutions can enable us to avoid harmful effects and generate beneficial effects on the environment and food security from genetically modified organisms (GMOs). This is done by analysing how institutions influence perspectives on GMOs, the GMOs that are developed and commercialized, as well as our ability to handle possible uncertain and unknown effects of GMOs. The thesis consists of 4 papers.

Paper 1 analyses scientists' perspectives on the release of GMOs into the environment, and the relationship between their perspectives and the institutional context that they work within, e.g. their place of employment (university or industry), funding of their research (public or industry) and their disciplinary background (ecology, molecular biology or conventional plant breeding). Q-methodology is employed to examine these issues. Two distinct perspectives are identified by interviewing 62 scientists. Perspective 1 is characterised by a moderately negative attitude to GMOs and the uncertainty and ignorance involved are emphasised. Perspective 2 is characterised by a positive attitude to GMOs and it is emphasised that GMOs are useful and do not represent any unique risks compared to conventional crops. The results show a strong association between scientists' perspective on GMOs and the explanatory variables training, funding and place of employment.

Paper 2 analyses how different institutional structures shape the research and development (R&D) of GMOs. Whether this R&D is conducted within companies, cooperatives or public research organisations is expected to influence the type of crops and traits that are developed and therefore the effects on society and ecosystems that potentially could follow from the use of GMOs. This issue is analysed empirically by statistical analysis of 1323 notifications for field trials with GMOs in the EU. The results show that the type of R&D organisation influences strongly the traits and crops that are developed.

Paper 3 analyses how the type of regulation for marketing of GMOs influences which GMOs that are commercialised. The EU and Norway have assessed the release of GMOs as commercial products quite differently. Of twenty four notifications approved by the EU, Norway has approved four, rejected ten, and has ten pending. The paper examines whether these differences could be explained by different judgments concerning the effects to be prevented and encouraged, response to uncertainty and

ignorance, and the burden of proof defined. Norwegian rejections are found to be explicable by the combination of no real benefit to society, lack of scientific knowledge, and involved risks. The main explanation for the EU approvals is that they see no reason to believe that there will be any adverse effects on health and the environment.

Paper 4 analyses how capable three different governance regimes are for adequate handling of uncertain and unknown effects of GMOs. GMOs are characterised by strong uncertainty. This implies that procedures for identification, reduction and monitoring of uncertainty, as well as how to treat irreducible uncertainty will be highly incomplete. Governance mechanisms that facilitate cooperative adaptation and communicative rationality (communicate with the intention of reaching agreement exclusively via the force of better arguments) are therefore needed. The three governance regimes compared are: GMOs are produced by private firms and these firms are made liable for harm (GR1), GMOs are produced by private firms and the government decides whether the crops should be marketed (GR2), GMOs are produced by public research organisations and the government decides whether the crops should be marketed (GR3). GR3 will be stronger in cooperative adaptation and communicative rationality than GR2. Public research organisations have fewer conflicts of interest with the government than private firms, and academic norms are important as opposed to firms where commercial norms are important. Difficulties in proving harm and identifying the responsible firm will make GR1 weak in cooperative adaptation and communicative rationality.

Based on the results of this thesis it is advised that consideration of the environment and food security justify institutional reforms concerning how we decide which GMOs that should be released into the environment and how we organise the R&D of GMOs. My analysis suggests that it is important to involve scientists from several disciplines in public marketing decisions on new technologies and that information about the contextual background of the scientists is relevant in these decisions. There are strong arguments for changing current practise where those that apply for marketing approval of GMOs also produce the risk assessment prior to marketing and the post marketing monitoring. It is further important to increase public GMO research to secure scientific advices and development of products that are independent from the priorities of the industry and to a greater extent could serve public needs.

**Sammendrag**

Denne avhandlinga er skrevet innenfor en moderne, klassisk institusjonell økonomisk tradisjon. Hensikten har vært å frambringe kunnskap om hvordan ulike institusjoner kan gjøre oss i stand til å unngå skadelige og å frambringe gunstige effekter av genetiske modifiserte organismer (GMOer) på miljø og matvaresikkerhet. Dette er gjort ved å analysere hvordan institusjoner påvirker perspektiver på GMOer, hvilke GMOer som utvikles og kommersialiseres, samt vår evne til å håndtere usikre og ukjente effekter av GMOer. Avhandlinga består av 4 artikler.

Artikkel 1 analyserer 62 forskeres syn på effekter av GMOer, og sammenhengen mellom synet deres og den institusjonelle konteksten de arbeider i, i form av type arbeidsplass (universitet eller industri), finansiering av forskning (offentlig eller privat) og fagdisiplin (økologi, molekylær biologi, eller tradisjonell planteforedling). Ved bruk av Q-metode ble to ulike syn identifisert. Syn 1 innebar en moderat negativ holdning til GMOer og vektla usikkerhet og uvitenhet. Syn 2 innebar en positiv holding til GMOer og vektla at GMOer er nyttige og ikke vesentlig forskjellige fra konvensjonelle landbruksvekster. Resultatene viser en sterk sammenheng mellom forskeres syn på GMOer og forklaringsvariablene utdanning, finansiering og type arbeidsplass.

Artikkel 2 analyserer hvordan ulike institusjonelle strukturer former forskning og utvikling (F&U) av GMOer. Vi forventa at om denne F&U blir gjort enten i private bedrifter, landbrukssamvirker, eller offentlige forskningsorganisasjoner påvirker hvilke arter og egenskaper som blir utvikla og dermed hvilke samfunns- og miljøeffekter som kan følge fra GMOer. Vi studerte dette ved hjelp av statistisk analyse av 1323 søknader om feltforsøk med GMOer i EU. Resultatene viser en sterk sammenheng mellom type forskningsorganisasjon og hvilke arter og egenskaper som blir utvikla.

Artikkel 3 analyserer hvordan type regulering for omsetning av GMOer påvirker hvilke GMOer som blir godkjent for kommersiell bruk. Den europeiske unionen (EU) og Norge har vurdert søknader om omsetning av GMOer forskjellig. Av 24 søknader som er godkjent av EU, har Norge godkjent fire, avvist ti og ikke tatt stilling til ti. Artikkelen analyserer om disse forskjellene kan forklares med ulike vurderinger av hvilke effekter som er ønska og uønska, hvordan man reagerer på usikkerhet og uvitenhent og hva som er en rimelig bevisbyrde. De norske avslaga kan forklares med at de ikke kunne se at GMO-søknadene hadde samfunnsmessig nytteverdi eller var bærekraftige, samt at de vektla uheldige miljøeffekter og mangel på vitenskapelig

kunnskap. Hovedforklaringen på godkjennelsene i EU er at de ikke fant noen grunner til at skadelige effekter ville inntreffe.

Artikkel 4 analyserer hvor egna tre ulike regimer er for å håndtere usikre og ukjente effekter av GMOer. Stor usikkerhet knytta til GMOer medfører at prosedyrer for å identifisere, redusere og overvåke usikkerhet, samt hvordan man skal håndtere ikke-reduserbar usikkerhet blir ufullstendige. Styringsmekanismer som legger til rette for samarbeidsvilje og kommunikativ rasjonalitet (kommunikasjon som har til hensikt å oppnå enighet ved bruk av argumenter) blir derfor viktig. Følgende tre regimer er sammenligna: GMOer produseres i private bedrifter og disse bedriftene er ansvarlige for eventuelle skader (R1), GMOer produseres i private bedrifter og myndighetene bestemmer hvilke GMOer som kan omsettes i markedet (R2), GMOer produseres i offentlige forskningsorganisasjoner og myndighetene bestemmer hvilke GMOer som kan omsettes i markedet (R3). Det er sannsynlig at R3 vill føre til bedre samarbeidsvilje og mer kommunikativ rasjonalitet enn R2. Offentlige forskningsorganisasjoner har færre interessekonflikter med myndighetene enn de private, og de er i større grad karakterisert av akademiske normer. Kommersielle normer har derimot en større plass i private bedrifter. Vanskeligheter med å bevise skade og skadegjører kan føre til at R1 gir svak samarbeidsvilje og lite kommunikativ rasjonalitet.

Funnene i avhandlingen innebærer at dersom hensyn til miljø og matvaresikkerhet er viktige, bør man gjennomføre institusjonelle endringer av hvordan man beslutter hvilke GMOer som kan omsettes i markedet og hvordan samfunnet organiserer F&U av GMOer. Min analyse antyder at det er viktig å involvere forskere fra ulike disipliner i offisielle beslutninger om hvilke GMOer som kan omsettes og at informasjon om den kontekstuelle bakgrunnen til disse forskerne er relevant. Det er sterke argumenter for å endre dagens praksis hvor de som søker om å få omsette GMOer i markedet også gjennomfører risikovurderingen og overvåkningen. Det synes videre viktig å øke andelen offentlig GMO-forskning for å sikre vitenskapelige råd som er uavhengige av industrienes prioriteringer og som i større kan tjene samfunnets interesser.

**Acknowledgements**

This thesis is written at the Department of Economics and Resource Management at the Norwegian University of Life Sciences. I want to express my gratitude to this department and my colleagues. My colleagues have given me many interesting and lively discussions and the department has been generous in providing opportunities for doing the course work and writing the thesis. I also would like to thank the administrative staff at the department for always being so helpful. A special thanks to Marianne Aasen and Katrine Soma whom I have been sharing office with. You have meant a lot for my well being as a PhD student. Finally, I would like to thank Ståle Navrud for sharing his excellent coffee and chocolate.

I did part of my course work at the Institute for Philosophy and Public Policy at Lancaster University. Being able to learn from lecturers like Brian Wynne, John Law, Phil Macnaghten and Robin Grove-White, being part of the professional and social activities at the institute and being able to spend time and develop friendship with especially Ariane Meier, but also some of the other students was very valuable for me as a person and as a PhD student.

I also want to express my gratitude to my current employer, the Norwegian Agricultural Economics Research Institute (NILF). NILF has been generous in providing time and resources for finishing the thesis and my colleagues have been supportive.

Frøydis Gillund, Kamilla Kjølberg and Per Kristian Rørstad deserve special thanks for contributing directly to the thesis. Frøydis and Kamilla are co-authors for one of the papers. Cooperating with them was very fruitful for my thesis and it created a lot of enjoyment. Per Kristian has provided valuable and important advices on Q methodology and I have appreciated being his colleague.

Arild Vatn has been my supervisor. Fortunately he was one of my lecturers when I was a cand.agric. student at the Department of Economics and Resource Management at the Norwegian University of Life Sciences. I appreciated what I learned from him and cooperating with him was one of the main motivations for doing a PhD. He has been quite extraordinary in providing inspiration, helpful ideas and advices as well as personal support during the whole period and he has made doing the PhD a meaningful process.

Finally I would like to thank my family. Without the help of my mother, Eli Kerstin Kvakkestad I would have finished much later. My mother in law, Åse Flaten,

has also been helpful in the finishing of the thesis. Ola Flaten, my husband, has supported me strongly in the process. He has made me more optimistic about my thesis, provided helpful advices and done a lot of extra housework. Thanks!

Alvdal, July 2010

Valborg Kvakkestad

**Table of Content**

# Introduction

A feature of the modern world is the rapid development of new technologies that potentially could have great – and often irreversible – impacts on humans and their interaction with the natural environment. Novel technologies often bring novel risks, which are hard or impossible to predict. Jaffe et al. (2003) emphasise that the environmental impact of human activity is profoundly affected by the rate and direction of technological change and that new technologies may create or facilitate increased pollution, or may mitigate or replace existing polluting activities. Technologies are furthermore shaped by the society and its institutional structures (Lam, 2002; Bijker, 1995[1]; Metcalfe, 1995; Westrum, 1991). By influencing which kind of considerations that can or should be taken into account in the development and adoption of new technologies, the institutional context will influence what types of technologies that are developed and adopted. What kind of incentives and motivations that are established for those who develop and adopt new technologies are therefore crucial for achieving sustainable development. Institutions for encouraging the development and diffusion of sustainable technologies as well as institutions that enable preventing environmental harm from potentially harmful technologies are needed. Grübler et al. (2002) emphasise that we do not yet have sufficient scientific knowledge about the sources and management of innovations to properly inform the policy-making process that affects technology-dependent domains such as agriculture and its' interaction with the environment.

Markets will not provide a social optimal amount of sustainable technologies or a social optimal diffusion of sustainable technologies (Aldy et al., 1998). This is explained by the fact that firms cannot fully appropriate rents from technology development and adoption; that the uncertainty associated with the returns to investment in innovation is often particularly large; and that firms cannot capture all the benefits of environmental services. Policy-makers should therefore compliment environmental policy with instruments designed explicitly to foster the development and diffusion of sustainable technologies (Jaffe et al., 2005). Foxon and Pearson (2008) emphasise that it is necessary to bring innovation and environmental policy regimes together. Policy for sustainable development may have different or even opposing objectives and imperatives to the goal of economic growth which usually underlies innovation policy (op. cit.). Sustainable technologies must often compete not only with components of an existing technology, but also with the overall institutional

[1] Bijker (1995) does not use the term 'institutions' but 'social factors'.

system in which it is embedded. This requires public policies to generate incentives for new technological systems that are more favourable to sustainable technologies, and to overcome barriers created by the prevalence of incumbent technologies or systems (op. cit.).

Institutions for dealing with negative environmental externalities from potential harmful technologies include market mechanisms like taxes and tradable permits. These systems do, however, not address the large uncertainty inherent in most environmental problems (Cornwell and Costanza, 1994). Flexible environmental assurance bonding system, designed to incorporate environmental criteria and uncertainty into market incentives or command and control measures might be more suited for dealing with uncertainty and technologies that might be socially undesirable. Prior to marketing, risk assessment by scientific experts and risk management by the policy makers represent the most common current policy measure for dealing with potential harmful technologies (Millstone, 2007). Various types of public participation with different stakeholders have been suggested to improve these processes (see for example Wiek et al., 2007; Funtowicz and Ravetz, 1992). These types vary from consulting the civil society in the decision-making processes to making citizens actively involved in the production, control and validation of science and technology (Bäckstrand, 2003) and may include consensus conferences, participatory technology assessment, citizen juries, public hearings and constructive technology assessment. Overall, public participation has been identified as one of the key factors for achieving a sustainable redesign of society (Elliott, 1997).

Genetically modified organisms (GMOs) are an example of a new technology that has the potential to influence both society and ecosystems in a novel way. This thesis is aimed at increasing our knowledge about which institutions that can enable sustainable use and development of GMOs. More specifically I examine scientists' perspectives on GMOs, and the relationship between their perspectives and the institutional context that they work within, how different institutional contexts shape the GMOs that are developed, how the formal institutions governing the release of GMOs in the EU and Norway influences which GMOs that are marketed and finally how different governance regimes enable us to deal with uncertain and unknown effects of GMOs.

The introduction starts by presenting the background of the thesis. This includes the importance of institutions for humans and their interaction, a brief presentation of GMOs and their potential environmental and socio-economic effects and the uncertainties involved. The purpose of the theses and a summary of the four papers are then presented. Finally, I examine what can be learned from this thesis and its policy implications.

## Institutions

This thesis is written within the contemporary classical institutional economics tradition. Institutions are here seen as the conventions, norms and formally sanctioned rules of a society (Vatn, 2005). Institutions shape, enable and constrain human choices by defining choice sets, by simplifying and regularising situations and by influencing our preferences, values and interests. The last aspect is what makes the classical institutional perspective distinct from other institutional tradition like new institutional economics[2] where the focus is on institutions as the constraints or choice set within which individuals act and choose.

Institutions shape individuals by defining social practices and assigning roles to the participants in these practices (Young, 2002). A role could be defined as "any relatively standardised social position, involving specific rights and obligations which an individual is expected or encouraged to perform" (Jary and Jary, 2000 p. 524). Being a scientist, mother, consumer, citizen, or house owner are all examples of roles that individuals take on. Roles define the goals or the interests that should be pursued, which acts are appropriate and which values that should be supported (Scott, 1995; Berger and Luckmann, 1967). According to this perspective the institutional context therefore influences which considerations that can or should be taken. The goals, interests, values and acts of for example a broker, a mother or a coach will differ. What is rational or reasonable to do does therefore depend on the institutional context. This context does, however, not determine entirely human choices. Individual factors also play an important role.

Institutions furthermore influence our perceptions. Individuals see nature and society through socially constructed concepts (Berger and Luckmann, 1967). Wynne (1992) emphasises for example that scientific 'facts' has to be actively read into nature. Language plays a crucial role in that respect by influencing the nature of our thinking about the world (Sapir, 1985; Whorf, 1956). Certainly, how nature is, influences our thinking about nature. However, as Metzner-Szigeth, (2009 p. 163) emphasises, our understanding of the world is also "products and constructs of social actions and social communication in their context of material and symbolical interaction between nature and society".

Formal rules are mainly important as forming constraints or choice sets within which individuals choose (Vatn, 2005). Formal rules are necessary when interests are strongly conflicting and norm building will be insufficient. The very essence of formal rules is exactly

[2] Important writers within this tradition are Douglass North, Oliver Williamson and Ronald Coase.

to protect certain interests (Bromley, 1989). A law that regulates who are allowed to pick berries and mushrooms in the forest will for example determine whether it is the land owners' interests or the interests of the landless that should be protected by the state.

Institutions do furthermore form an important part of governance as governance concerns "the different ways in which societies can organise themselves to accomplish their goals" (de Loë et al., 2009 p. iii). The chosen governance regime will influence which types of motivations that are fostered and thereby which kind of considerations that can or should be taken into account.

**GMOs and their (potential) social and environmental effects**

GMOs are organisms whose genetic material has been altered by the use of recombinant DNA techniques for gene transfer (Thompson, 2003). These techniques are employed to produce organisms whose genomes have been altered at the molecular level, usually by the inclusion of genes from unrelated species of organisms that code for traits that would not be obtained easily through conventional selective breeding (Encyclopædia Britannica, 2009). Today, the majority of the GMOs that are deliberately released or developed for deliberate release into the environment are genetically modified (GM) crops. In 2008 four crops (soybean, maize, cotton and canola) and three types of traits (herbicide tolerance, stacked[3] traits and insect resistance) occupied more than 99 percent of the global GM crop area (James, 2008). We also observe concentration in the companies that develop GM crops (Fulton and Giannakas, 2001). An example is that 58 percent of all field trial notifications in the EU were submitted by 3 companies in the period 2008-2009.

The deliberate release of GM crops into the environment has been highly controversial in some parts of the world and been subject to polarised debate within the scientific community (Lacy et al., in press). Concerns have been raised about possible environmental effects, health effects, socio-economic effects as well the possibility for uncertain and unknown effects. This section gives a brief presentation of possible environmental and socio-economic effects. Health effects are not a part of this thesis and are therefore excluded from the analyses.

[3] If more than one gene from another organism has been transferred, the GM crop has stacked traits. The most usual combination are crops that confer resistance to insect pests and herbicide tolerance.

*Environmental effects*

The environmental effects of cultivating GM crops depend on the gene(s) that are inserted, the species of the crop plant, the environment into which it is introduced and the management of its cultivation (Ervin et al., 2000). Effects of GM crops could further result from either the GM crop itself, gene transfer to other organisms or changes in agricultural practice.

A possible environmental effect of GM crops is invasiveness in natural habitats (Conner et al., 2003). This is most likely for GM crops that are tolerant to extreme temperatures and soil salinity or GM crops that are resistant to pests or pathogens or changes in seed dormancy and propagation characteristics (Dale et al., 2002). GM crops could also have other non-target effects on organisms in their environment (Craig et al., 2008). These effects could both be direct and indirect. Insect resistant GM crops could for example harm non-target butterflies directly (Aviron et al., 2009). An indirect effect that is documented from the cultivation of some herbicide tolerant crops is reduced bird abundance due to the removal of weeds from crops (Chamberlin et al., 2007).

Certain GM crops like pest resistant and herbicide tolerant GM crops might affect pesticide use. Current insect-resistant and herbicide tolerant GM crops may decrease the use of environmentally harmful pesticides in the short run (Wolfenbarger and Phifer, 2000). The long run environmental effect of these crops might, however, depend on whether they increase resistance problems and thereby eliminate the benefits or increase the use of harmful pesticides (op. cit.). Weed resistant to herbicides can develop by increased selection pressure when continually sprayed with the same herbicide or by gene flow from a herbicide tolerant crop. Insect pests could become resistant because of widespread use of insect resistant crops (Dale et al., 2002).

Improved soil conservation might follow from the cultivation of herbicide tolerant GM crops by enhancing the possibilities of conservation tillage practices that can reduce soil erosion and water loss (Cannell and Hawes, 1994). The cultivation of GM crops might also increase yield and thereby contribute to the preservation of biodiversity since less land may be needed for agriculture (Cattaneo et al., 2006). Another potential environmental benefit from recombinant DNA techniques is the development of GM crops that may provide rehabilitation of toxic waste sites (Barton and Dracup, 2000). GM crops might also provide an environmentally friendly alternative to certain environmentally harmful production activities. Biotechnology might for example improve the production of bio fuels (James, 2008).

Most of the above mentioned effects are only relevant for some types of GM crops and most of the effects are not unique for GM crops. GM traits like herbicide tolerance could for

example result from both conventional and GM technologies (Barton and Dracup, 2000). It is further the case that both conventional crops and GM crops for example could become invasive, increase yields and have non-target effects. A crucial and highly debated issue is therefore whether there are reasons to believe that GM crops represent any more significant risks than other types of crops. It is being argued that genetic engineering result in a more precise and well-characterised introduction of genetic novelty than conventional approaches do, variability and unexpected results should therefore be less in GM crops than in conventionally bred crops (Thompson, 2003). Others, like The GM Science Review Panel (2003), argue that the transfer of genes across the species barrier raises the possibility that some unexpected consequences of GM plant breeding may appear. Wolfenbarger and Phifer (2000) emphasise that it is exactly the transfer of genes across the species barriers that creates the greater potential, as well as risk of genetic engineering by providing a greater range of possibilities for transferring desired genotypes into organisms.

*Socio-economic effects*

The general public has raised concerns about socio-economic effects of GM crops. This has especially been the case in Europe where, overall, the general public thinks that GM crops should not be encouraged and they do not see any real social benefits from this technology (Gaskell et al., 2006). Results from focus groups in five European countries show that lay people do not react so much to genetic modification as a specific technology, but rather to the institutional context in which GM crops have been developed, evaluated and promoted (Marris, 2001).

One of the main concerns has been the dominance of multinational corporations in the R&D of GM crops. Lack of trust in these companies, the impression that these companies are the primary beneficiaries of biotechnology as well as concerns about the growing control of multinational corporations over farming contributes to opposition to GM crops (Priest et al., 2003; Moon and Balasubramanian, 2001). Lay people believe that these companies are motivated by profit rather than meeting society's needs, and that they have the power to make their interests prevail over the wider public interest (GM PDSB, 2003). Even when people acknowledge potential benefits of GM technology, they are doubtful that GM companies will actually deliver them (GM PDSB, 2003). It is further feared that the widespread use of patenting in plant biotechnology will give these companies control over the resources of crop production and reproduction (ESRC, 1999).

The public has also raised concerns abut the regulation of GM crops. This includes too little weight given to socio-economic considerations, uncertainty and the view of the general public as well as the impression that economic interests often overrides health and environmental considerations (Gaskell et al., 2006; Marris et al., 2002). Lay people do further emphasise that the use of GM crops are a further stage in the industrialisation of agriculture, that they are a symbol of the assault on traditional sources of food and that they are 'unnatural' (Lacy et al., in press; GM PDSB, 2003). Unnaturalness is related to the idea that scientists do not know the full extent of their work, and can not know the long-term consequences of their actions on ecosystems, human health and social relations (Marris, 2001).

Benefits for farmers and consumers in developing countries, and thereby possibilities for alleviation of poverty and hunger are seen as the main potential social advantages of GM crops by the public (GM PDSB, 2003). Farmers and consumers in developed countries might also benefit in the form of lower costs of production and higher productivity (James, 2008). Consumers might experience reduced food prices and increased food quality (Lacy et al., in press). Other perceived socio-economic benefits from agricultural biotechnology include increased employment and economic growth and thereby possibilities to secure future wealth (Sinemus and Egelhofer, 2007).

**Uncertainty**

In the previous section it was emphasised that one of the main concern related to GM crops concerns lack of knowledge and ability to predict effects of GMOs. To understand the implications of lacking predictability, it is important to distinguish between risk, uncertainty and ignorance. Knight (1921) made an important distinction between risk and uncertainty in the way that risk implies known outcomes with known probabilities, while uncertainty means known outcomes but unknown probabilities. A situation where even the outcomes are unknown is defined as ignorance (Shackle, 1955). These concepts relate to the external world (how the world is, was or will be) and to knowledge of the external world (what we can determine about the status of the world) (Strand et al., 2009). Uncertainty and ignorance can therefore both be reducible and irreducible. Reducible uncertainty and ignorance can be abridged by producing more scientific knowledge, while irreducible uncertainty and ignorance can not (Faber et al., 1996; Wynne, 1992). Uncertainty can be irreducible due to measurement problems (Spash, 2002) and ignorance can be irreducible due to the intrinsic

complexity or indeterminacy of many natural and social processes and the incompleteness of scientific methods (Stirling, 1998). What humans will do in the future is indeterminate (Jamieson, 2000) and ecosystems are complex, dynamic and unpredictable across space and time (Moore et al., 2009). When scientists are dealing with complex systems, they will also be unable to develop a coherent, unified picture of 'the environment' that everyone can agree on (Sarewitz, 2004). Several legitimate interpretations of identical observations are then possible (Stirling et al., 2007).

We have to make a distinction between our knowledge about probabilities and outcomes and our beliefs about our knowledge about probabilities and outcomes. We could believe that our knowledge about an issue is characterised by risk or uncertainty, while in fact it is characterised by ignorance, and we could believe *ex ante* that unknown effects will occur, while it turns out *ex post* that no unknown effects occurred. It is further important to be aware that we can never know *ex ante* whether ignorance is reducible or irreducible (Faber et al., 1996). Judgements concerning the extent to which we don't know what we don't know and how to deal with uncertainty and ignorance are intrinsically subjective and value laden (Stirling, 1998). We do, however, know that in situations where complex natural systems are interlinked with complex social systems and scientists disagrees strongly, uncertain and unknown effects might occur. This is exactly the case with GMOs. Wolfenbarger and Phifer (2000) emphasise that GMOs will be introduced into complex ecosystems, and that not every risk associated with the release of new organisms, including GMOs, can be identified, much less considered. The effects of GMOs will further depend on decisions made by a variety of different social actors, including millions of farmers worldwide (Jamieson, 2000).

**Purpose of the thesis**

From the previous sections we have learned that (1) institutions protect and shape interests, values and goals and they influence our perceptions, (2) that GMOs can have both positive and negative effects depending on the gene(s) that are inserted, the species of the crop plant and management, that (3) there is substantial scientific disagreement on whether GMOs represent more significant risks than other types of organisms, and that (4) parts of the public, especially in Europe, have reacted negatively to the institutional context in which GMOs have been developed and evaluated. It is furthermore the case that some scientists and lay people fear uncertain and unknown consequences of GMOs. This uncertainty forces specific challenges on public decision-making.

The purpose of this thesis has been to provide insight about **how different institutions can enable us to avoid harm and to generate beneficial effects of GMOs with specific focus on environmental aspects and food security.** This issue is examined by analysing how institutions influence perspectives on GMOs among scientists (paper 1), which GMOs that is developed (paper 2), which GMOs that is commercialised (paper 3) as well as our ability to handle possible uncertain and unknown effects of GMOs (paper 4). While paper 3 concerns GMOs in general, the other papers only concerns GM crops. The institutions included in the analysis are, disciplinary background, research funding (private and public), type of R&D organisation (university or company), regulations for marketing of GMOs and type of governance regime. The aspects of a governance regime that is studied is what type of entities (the state or private companies or the civil society) that are involved in the production, prior to marketing assessment, post market monitoring and the marketing decision on GMOs.

Table 1 presents an overview of these institutions and which of their influences are analysed.

*Table 1: Institutions analysed in the thesis and which of their influences are analysed*

| **Institutions analysed** | **Influence on** |
|---|---|
| Disciplinary background | Perspective on GMOs |
| Type of research funding (private or public) and type of R&D organisation (university or company) | Perspective on GMOs and GMOs that are developed |
| Regulation for marketing of GMOs | GMOs that are commercialised |
| Governance regime (which entities should produce, assess, decide on marketing and monitor GMOs.) | Ability to handle possible uncertain and unknown effects of GMOs |

I expected the institutions mentioned in Table 1 to be important for which considerations that can and should be taken into account in the development and evaluation of GMOs. Disciplinary background, funding and type of R&D organisation are important for the role that scientist take on and thereby for the obligations a scientist is expected or encouraged to stand up to. Being an ecologist or molecular biologist might influence what aspects of biological systems that are studied and the assumptions made concerning our ability to predict

and control nature. The obligations of industry scientists and university scientists differ. Public research should ideally serve public needs and intellectual inquiry while private companies should maximise profits. One would expect topics and issues that are external to the market place to be less important under industry research than for university research. Regulations for marketing of GMOs will define which issues are relevant in the evaluation of GMOs. The chosen governance regime will influence which kind of considerations can or should be taken into account and thereby our ability to handle uncertain and unknown effects of GM-crops. Whether those that are involved in the production, assessment, monitoring and decision making on the marketing of GM crops act in the role of the state, the role of a private company or the role of a citizen will influence the motivations involved.

**Paper 1: Scientists' Perspectives on the Deliberate Release of GM Crops**

This paper analyses scientists' perspectives on the release of GM crops into the environment, and the relationship between their perspectives and the institutional context that they work within, e.g. their place of employment (university or industry), funding of their research (public or industry), their disciplinary background (ecology, molecular biology or conventional plant breeding) and type of research (applied, basic or risk research). It is important to study these issues since scientists play a key role in the introduction of new technologies. They are often the ones that develop these technologies and the ones that are called as experts to evaluate the safety of new technologies.

We employed Q-methodology and logistic regression to examine these issues. Q methodology is a type of discourse analysis that enables the identification of common patterns of opinion held by a certain group of people. Respondents were asked to sort a given number of statements, in relation to each other, according to an evaluative profile ranging from agree to disagree. These individual Q sorts were factor analysed to identify patterns of communality and divergence in expressed viewpoints. Two distinct factors were identified by interviewing 62 Scandinavian scientists. These two factors included 92 per cent of the sample.

Factor 1 scientists had a moderately negative attitude to GM crops and strongly emphasised the unpredictability of the environmental effects of GM crops, while they had no strong opinion on claimed positive consequences of GM crops and whether GM crops are fundamentally different from conventional crops. The presence of negative consequences of growing GM crops is moderately emphasised. This means that less emphasis is put on known possible harmful effects than on unpredictability. They had little confidence in gene technology research undertaken by industry. Factor 2 scientists had a positive attitude to GM

crops and strongly emphasised that GM crops are not fundamentally different from conventional crops and that these crops are likely to have major positive consequences. They had no strong opinion on the predictability of the environmental effects of GM crops or on potential negative impacts from growing GM crops. They had confidence in gene technology research undertaken by industry.

The contextual characteristics of the scientists revealed a clear pattern concerning the perspective they hold on GM crops. All the industry-employed scientists held perspective 2, while university-employed scientists were associated with both perspectives. Scientists that have some type of industry involvement[4] were very likely to be associated with perspective 2, while scientists that only receive public funding were somewhat more likely to hold perspective 1 than perspective 2. None of the ecologists held perspective 2, while 73 % of the molecular biologists held perspective 2 and 67 % of the conventional plant breeders held perspective 1. Type of research had no significant effect.

**Paper 2: Institutions and the R&D of GM crops**

This paper analyses how different institutional structures shape the research and development (R&D) of GM crops. Whether this R&D is conducted within private companies, cooperatives or public research organisations is expected to influence the type of crops and traits that are developed and therefore the effects on society and ecosystems that potentially could follow from the use of GM crops. The fact that crops are biological products that are easily reproduced imply certain obstacles for creating the necessary economic returns in markets. Company research does therefore require products with some kind of excludability. Legal means to secure profits like plant variety protection, patents, and contract growing provide incomplete, protection for GM seeds (Srinivasan and Thirtle, 2003). I therefore expected company research to focus on R&D that makes crops biologically excludable to secure return on private investments. Biological means for making crops excludable include the development of v-gurts (terminator seeds), hybrid seeds, and herbicide-tolerant crops that are developed by an organisation that also market the particular herbicide. I further expected company research to focus on crops and traits that are widely demanded and crops and traits that can be developed at sufficiently low costs. Public research organisations were expected to be more likely to focus on issues that are external to the market like environmental and food security effects than the other types of R&D organisations.

[4] University-employed scientists that have some industry funding or are purely industry funded, and industry-employed scientists.

These issues are analysed empirically by statistical analysis of 1323 notifications for field trials with GM crops that have been submitted under two EU Directives in seven European countries. By five logistic regression models I examined whether the share of biologically excludable crops, the share of crops that is widely grown, the share of traits that are inexpensive to develop and the share of biosafety research depends on the interest and the country that are involved in the R&D of GM crops. I also included the time period when the notification was submitted. 'Interest' refer to different combinations of type of organisation (company, cooperative, public research organisation) and funding (private or public) and include 'company', 'cooperative mix'[5], 'public mix'[6], and 'pure public'[7]) I expected the share of excludable GM crops that are widely grown and/or include traits that are inexpensive to develop to be greatest in companies, followed by 'cooperative mix', 'public mix', and 'pure public'. I expected the share of biosafety research to be greatest in 'pure public', followed by 'public mix', 'cooperative mix' and 'company'.

Generally, the analyses of the models supported the hypotheses. Exceptions were that 'cooperative mix' not differ significantly from 'public mix' for crops that are made biological excludable by biotechnology and crops that are widely grown, that 'public mix' not differ significantly from 'pure public' for crops that are widely grown and traits that are inexpensive to develop, and that 'cooperative mix' does not differ significantly from 'pure public' for traits that are inexpensive to develop. For biosafety research there is one significant difference between the interests. 'Company' differs from all the others. Hence 'company' stands out as the interest that always come out different from the other interests, while the other interests sometimes differ significantly from each other and sometimes not. Another important finding is that only 3 percent of the notifications concerned no other purpose than biosafety research.

These results indicate that consideration of the environment, food safety and food security might justify institutional reforms of R&D of GM crops. Biological excludable crops might increase agricultural weed-management problems and affect food security negatively if the supply of seeds to farmers is hampered. Increased biosafety research is important to produce knowledge about negative effects on the environment, food security and food safety of GM crops. These reforms might include increased public funding combined with less use of legal means to secure profits.

[5] R&D projects that have some kind of cooperative involvement. Cooperatives are included in this category because the database contains only a few pure cooperatives.
[6] R&D projects that have both public and private involvement.
[7] R&D projects that only have public involvement.

**Paper 3: Regulating the Release of GMOs: Contrasts between the European Union and Norway**

This paper analyses how the type of regulation for marketing of GMOs influences which GMOs that are commercialised. The EU and Norway have assessed the release of GMOs as commercial products quite differently. Of 24 notifications approved by the European Union between 1993 and 2007, Norway has approved 4, rejected 10, and has 10 pending. We examine whether these differences could be explained by different value judgments made in the formulation and implementation of regulations for commercialisation of GMOs. Three aspects are discussed: the effects to be prevented and encouraged, response to uncertainty and ignorance, and the burden of proof. An important implication of uncertainty and ignorance is that value judgments concerning how the burden of proof should be framed become crucial for decisions on GMO release. Proving harm and proving safety may be impossible. Finally, we analyse how these value issues are treated, i.e. whether they actually are treated as value issues or merely as technical issues.

The methods used are analyses of public documents and interviews with civil servants in the European Commission and Norway. The Norwegian and the EU regulations require that those who want to release GMOs into the environment should submit a notification that contains a prior risk assessment of health and environmental effects. The two regulations are, however, unclear on which health and environmental effects that is unwanted. The prior assessments that have been undertaken in the EU and Norway include almost the same health and environmental effects. Some of the properties of the GMOs are, however, evaluated as more harmful for health and environment in the Norwegian decisions than in the EU decisions. The Norwegian regulation also requires that effects on sustainable development and benefits to society should be evaluated and it has been concluded that the notifications provide no real benefit to society.

The Norwegian regulation emphasises that the existence of uncertainty and ignorance direct against approval while the EU regulation is unclear on this. In all the 24 EU approvals, it was concluded that there is no reason to believe that there will be any adverse effects on human health or the environment. The Norwegian government has made a similar conclusion in three of the approvals, while they have rejected most of the cases, by emphasising lack of scientific knowledge. Hence, the Norwegian decisions and the EU decisions have responded quite differently to uncertainty and ignorance.

The burden of proof applied is similar in terms that the notifiers have to provide tests or studies of certain harmful effects. The authorities have then decided whether these studies

are sufficient. In all of the notifications, the notifier has concluded that the tests have not identified any harmful effects. The EU authorities have defined these tests to be sufficient, while the Norwegian authorities have only found the studies to be sufficient in three of the approvals.

The combination of no real benefit to society, lack of scientific knowledge, and involved risks explains the Norwegian rejections, while the main explanation for the EU approvals is that they saw no reason to believe that there would be any adverse effects on health and the environment. In the EU, several value issues are decided on by experts, while the Norwegian decision-making procedure has, to a greater extent, treated decisions on the release of GMOs as a value issue. The problem is not that value judgments may differ. What is problematic is when procedures are such that value judgments are treated as technical issues and conducted by experts.

**Paper 4: Governing uncertain and unknown effects of genetically modified crops**

This paper analyses the capabilities of three different governance regimes for adequately handling of uncertain and unknown effects of GM crops. Adequate handling requires the development of sound procedures for identification of uncertainty and ignorance (U&I), reduction of U&I (if possible), decisions on how to treat irreducible U&I and monitoring of unexpected effects. The nature of U&I implies, however, that these procedures will be highly incomplete. It is impossible to develop *ex ante* instructions that specify in advance adequate responses to new information/knowledge, how U&I should be identified and reduced, how to make sound decisions in the case of irreducible U&I, and how monitoring should be conducted. Asset specificity, i.e. that each GM crop is unique with respect to potential environmental effects, implies that it would be impossible to develop regulations that are adjusted to each GM crop variety. We further find ourselves in a situation of asymmetric information between the producers and the regulator, because the producers are better informed about the GM crop that they have developed than the regulator.

Faced with incomplete procedures and therefore situations where contingent events and countermove strategies are rich beyond description, governance mechanisms that facilitate cooperative adaptation and communicative rationality are needed. Cooperative adaptation refers to a capacity and predisposition toward responding to disturbances in a coordinated and compliant way (Williamson, 1999) while communicative rationality implies communication with the intention of reaching agreement exclusively via the force of better

arguments (Habermas, 1984). The communications should be free from manipulation and coercion and the participants should act on "higher" motives than their own interests.

Williamson (1999) emphasises that the efficient governance response to the need for cooperative adaptation is to provide contractual safeguards. If unmet needs for added coordination persist, the solution is to internalise the hazard through unified ownership/vertical integration. Transferred to our study, the important question becomes which of the following governance regimes (GR) is the best response to the need for cooperative adaptation and communicative rationality:

1. GM crops are produced by private firms and these firms are made liable for harm. A monitoring regulation is established that requires monitoring by the firm (GR1a) or monitoring by a public regulatory body (GR1b).
2. GM crops are produced by private firms and the government decides whether the crop should be marketed. An assessment and monitoring regulation is established that requires assessment and monitoring by the firm (GR2a) or assessment and monitoring by a public regulatory body (GR2b).
3. GM crops are produced by public research organisations and the government decides whether the crop should be marketed. An assessment and monitoring regulation is established that requires assessment and monitoring by the public research organisation (GR3a) or assessment and monitoring by a public regulatory body (GR3b).

The effect of bringing the civil society into the decision-making process is also analysed. According to our analyses, it is likely that GR3b will handle U&I most adequately, followed by GR3a or GR2b; next are GR2a or GR1b, and finally GR1a. Firms are responsible to private interests only, whereas public research organisations have a duty to the state and the general public. Public research organisations therefore have fewer conflicts of interest with the regulatory body and the government than private firms and will be stronger in cooperative adaptation than private firms. The importance of academic norms in public research organisations versus the importance of commercial norms in firms also implies that public research organisations will be stronger in communicative rationality than private firms. Difficulties in proving harm and identifying the responsible firm will make liability regimes weak in cooperative adaptation and communicative rationality. Assessment and monitoring of U&I by a public regulatory body and marketing decision making by the government will reduce possibilities for lack of cooperative adaptation and provide stronger possibilities for communicative rationality compared with assessment, marketing decision making and

monitoring by firms or public research organisations. These conclusions do, however, depend on how far the blurring of society's stable categorisations has gone and whether the government favours adequate handling of U&I of GM-crops. Reversing the commercialisation of public research and including civil society in the public decision-making process are important to ensure that GR3 actually will facilitate adequate handling of U&I.

**Lessons learned from the thesis and their policy implications**

From this thesis we have learned that institutions are important for the perspectives that are held on GMOs, the GMOs that are developed and the GMOs that are marketed. More specifically we have learned that:

- Scientists hold opposing perspectives on the reasonability of releasing GMOs into the environment and these perspectives depend on disciplinary background, place of employment (university or private company) and funding (public or private).
- Whether the R&D of GMOs is conducted within companies, cooperatives or public research organisations influence the type of crops and traits that are developed and therefore the effects on society and ecosystems that potentially could follow from the use of GMOs.
- Different judgments made in the formulation of regulatory documents and the implementation of these documents regarding response to uncertainty and ignorance, burden of proof, and which effects should be prevented and encouraged are crucial for the final decisions on whether or not to approve GMOs for commercialisation. These judgments are often treated as technical issues and conducted by experts.
- The involvement of public research organisations in the R&D of GMOs and public regulatory bodies and the civil society in the assessment and monitoring of GMOs increases the likelihood for adequate handling of uncertain and unknown effects of GMOs compared to a situation where these tasks are conducted by private companies.

The policy implications from these results will of course depend on which political goals that are emphasised. Consideration of the environment and food security might justify institutional reforms concerning how we decide which GMOs that possibly should be released into the environment and how we organise the R&D of GMOs.

The empirical results of this thesis show that it is important to involve scientists from several disciplines in public marketing decisions on new technologies and that information about the contextual background of the scientists is relevant in these decisions. It is further

important to be aware that deciding which GMOs should possibly be released is neither self-evident nor only a factual matter. This is partly due to the uncertainties involved. It is important to ensure that value issues are not treated as technical issues and decided on by experts. From other studies (e.g. Gaskell et al., 2006, GM PDSB, 2003, Marris et al., 2002) it follows that if public concerns should be taken into account, it is important that the assessment not merely concerns health and environmental effects. There are strong arguments for replacing the current practise where those that apply for marketing approval of GMOs also produce the risk assessment prior to marketing and the post marketing monitoring with a procedure that makes public regulatory bodies responsible for prior to marketing assessment and post marketing monitoring. Involving participants from the civil society in the decision-making process are important to ensure that shared/public interests and values are articulated, fostered and served.

From the perspective and results of this thesis, it becomes important to turn the commercialisation of GMO research to secure scientific advices and development of products that are independent from the priorities of the industry and to a greater extent could serve public needs. The realisation of GMOs with net positive effects on the environment and food security might require increased public R&D since these issues represent, in general, benefits and costs external to the private sector. Public R&D will be needed to ensure that GMOs can benefit sustainable small-farm agriculture in developing countries (Serageldin, 1999) and public R&D are likely to imply more adequate handling of possible uncertain and unknown effects. It is further important to increase the amount of public biosafety research. Politicians should, however, be aware that not all uncertainties can be resolved with more research.

The fact that organisms by their very nature are non-excludable does also favour increased public R&D of GMOs. Legal excludability (e.g. through intellectual property rights or contract growing) makes R&D and cultivation of crops more bureaucratic and extensive use of intellectual property rights may contribute to a more concentrated industry structure (UNCTAD, 2006). Biological excludability is not in itself advantageous for crop production and might imply certain negative effects on the environment and food security. It would have been better for the society if crop developers could use their creativity on other issues than making crops excludable.

Finally, it is important to be aware that public research is not a sufficient condition for avoiding harm and generating positive effects on the environment and food security. Upstream public engagement, more interdisciplinary research, less competitive pressure and less market oriented research are important to increase the social value of public R&D.

**References**


Aldy, J.E., Hrubovcak, J., Vasavada, U., 1998. The role of technology in sustaining agriculture and the environment. Ecological Economics 26, 81–96.

Aviron, S., Sanvido, O., Romeis, J., Herzog, F., Bigler, F., 2009. Case-specific monitoring of butterflies to determine potential effects of transgenic Bt-maize in Switzerland. Agriculture, Ecosystems & Environment 131, 137–144.

Barton, J.E., Dracup, M., 2000. Genetically modified crops and the environment Agronomy Journal 92, 797–803.

Bäckstrand, K., 2003. Civic science for sustainability: reframing the role of experts, policy-makers and citizens in environmental governance. Global Environmental Politics 3, 24–41.

Berger, P., Luckmann, T., 1967 (reprinted 1991). The Social Construction of Reality. A Treatise in the Sociology of Knowledge. Penguin, London.

Bijker, W.E. 1995. Sociohistorical technology studies, in: Jasanoff, S., Markle, G.E, Petersen, J.C., Pinch, T. (Eds.), Handbook of Science and Technology Studies. Sage publications, London, pp. 229–256.

Bromley, D.W., 1989. Economic Interests and Institutions. The Conceptual Foundations of Public Policy. Basil Blackwell, Oxford.

Cannell, R.Q., Hawes, J.D., 1994. Trends in tillage practices in relation to sustainable crop production with special reference to temperate climates. Soil and Tillage Research 30, 245–282.

Cattaneo, M.G., Yafuso, C., Schmidt, C., Huang, C.Y., Rahman, M., Olson, C., Ellers-Kirk, C., Orr, B.J., Marsh, S.E., Antilla, L., Dutilleu, P., Carriere, Y., 2006. Farm-scale evaluation of the impacts of transgenic cotton on biodiversity, pesticide use, and yield. Proceedings of the National Academy of Sciences of the United States of America 103, 7571–7576.

Chamberlain, D.E., Freeman, S.N., Vickery, J.A., 2007. The effects of GMHT crops on bird abundance in arable fields in the UK. Agriculture, Ecosystems & Environment, 118, 350–356.

Conner, A.J., Glare, T.R., Nap, J.P., 2003. The release of genetically modified crops into the environment - Part II. Overview of ecological risk assessment. Plant Journal 33, 19–46.

Cornwell, L., Costanza, R., 1994. An experimental analysis of the effectiveness of an environmental assurance bonding system on player behavior in a simulated firm. Ecological Economics 11, 213–226.

Craig, W., Tepfer, M., Degrassi, G., Ripandelli, D., 2008. An overview of general features of risk assessments of genetically modified crops. Euphytica 164, 853–880.

Dale, P.J., Clarke, B., Fontes, E.M.G., 2002. Potential for the environmental impact of transgenic crops. Nature Biotechnology 20, 567–574.

de Loë, R.C., Armitage, D., Plummer, R., Davidson, S., Moraru, L., 2009. From government to governance: a state-of-the-art review of environmental governance. Final Report. Prepared for Alberta Environment, Environmental Stewardship, Environmental Relations. Rob de Loë Consulting Services, Guelph.

Elliott, D., 1997. Energy, Society and Environment. Routledge, London.

Encyclopædia Britannica Online, 2009. Genetically modified organism. http://search.eb.com/eb/article-9443507

Ervin, D., Batie, S., Welsh, R., Carpentier, C.L., Fern, J.I., Richman, N.J., Schulz, M.A., 2000. Transgenic crops: an environmental assessment. Policy Studies Report. Henry A. Wallace Center for Agricultural and Environmental Policy at Winrock International. http://www.winrock.org/wallace/wallacecenter/documents/transgenic.pdf.

ESRC (Economic and Social Research Council, Global Environmental Change Programme), 1999. The politics of GM food: risk, science and public trust. Special Briefing No. 5. University of Sussex, Falmer.

Faber, M., Manstetten, R., Proops, J., 1996. Ecological Economics: Concepts and Methods. Edward Elgar, Cheltenham.

Foxon, T., Pearson, P., 2008. Overcoming barriers to innovation and diffusion of cleaner technologies: some features of a sustainable innovation policy regime. Journal of Cleaner Production 16S1, 148–161.

Fulton, M., Giannakas, K., 2001. Agricultural biotechnology and industry structure. AgBioForum 4, 137–151.

Funtowicz, S.O., Ravetz, J.R., 1992. Three types of risk assessment and the emergence of post-normal science, in: Krimsky, S., Golding, D. (Eds.), Social Theories of Risk. Praeger, London, pp. 251–273.

Gaskell, G., Allansdottir, A., Allum, N., Corchero, C., Fischler, C., Hampel, J., Jackson, J., Kronberger, N., Mejlgaard, N., Revuelta, G., Schreiner, C., Stares, S., Torgersen, H., Wagneret, W., 2006. Europeans and biotechnology in 2005: patterns and trends. Eurobarometer 64.3. A report to the European Commission's Directorate-General for Research. European Commission, Brussels.

GM PDSB, 2003. GM Nation? The findings of the public debate. Report of the GM Public Debate Steering Board. Department of Trade and Industry, London.

GM Science Review Panel, 2003. GM science review, first report. An open review of the science relevant to GM crops and food based on interests and concerns of the public. http://www.gmsciencedebate.org.uk/report/pdf/gmsci-report1-full.pdf.

Grübler, A., Nakicenovic, N., Nordhaus, W.D., 2002. Induced technological change and the environment: an Introduction, in: Grübler, A., Nakicenovic, N., Nordhaus, W.D. (Eds.), Technological Change and the Environment. RFF Press, Washington DC, pp. 1–8.

Habermas, J., 1984. The Theory of Communicative Action. Vol I: Reason and the Rationalization of Society. Beacon Press, Boston.

Jaffe, A.B., Newell, R.G., Stavins, R.N., 2003. Technological change and the environment, in: Mäler, K.G., Vincent, J.R. (Eds.), Handbook of Environmental Economics, vol. 1. Elsevier Science, Amsterdam, pp. 461– 516.

Jaffe, A.B., Newell, R.G., Stavins, R.N., 2005. A tale of two market failures: technology and environmental policy. Ecological Economics 54, 164–174.

James, C., 2008. Global status of commercialized Biotech/GM crops. ISAAA Brief No. 39. The International Service for the Acquisition of Agri-biotech Applications (ISAAA), Ithaca.

Jamieson, D., 2000. Discourse and moral responsibility in biotechnical communication. Science and Engineering Ethics 6, 265–273.

Jary, D., Jary, J., 2000. Collins Dictionary of Sociology, third edition. Harper Collins Publishers, Glasgow.

Knight, F.V. 1921. Risk, Uncertainty and Profit. Houghton Mifflin Company, Boston.

Lacy, W.B., Glenna, L., Biscotti, D., Welsh, R., in press. Agricultural biotechnology, socioeconomic effects, and the fourth criterion, in: Seidel, A. (Ed.), Wiley Encyclopedia of Industrial Biotechnology.

Lam, A., 2002. Alternative societal models of learning and innovation in the knowledge economy. International Social Science Journal 54, 67–82.

Marris, C., 2001. Public views on GMOs: deconstructing the myths. EMBO reports 2, 545–548.

Marris, C., Wynne, B., Simmons, P., Weldon, S., 2002. Public perceptions of agricultural biotechnologies in Europe. Final Report of the PABE Research Project. http://csec.lancs.ac.uk/pabe/docs.htm.

Metcalfe, S., 1995. The economic foundation of technology policy: equilibrium and evolutionary perspectives, in: Stoneman, P. (Ed.), Handbook of the Economics of Innovations and Technological Change. Blackwell, Oxford, pp. 409–512.

Metzner-Szigeth, A., 2009. Contradictory approaches? On realism and constructivism in the social sciences research on risk, technology and the environment. Futures 41, 156–170.

Millstone, E., 2007. Can food safety policy-making be both scientifically and democratically legitimated? Is so, how? Journal of Agricultural and Environmental Ethics 20, 483–528.

Moon, W., Balasubramanian, S.K., 2001. Public perceptions and willingness-to-pay a premium for non-GM foods in the US and UK. AgBioForum 4, 221–231.

Moore, S.A., Wallington, T.J., Hobbs, R.J., Ehrlich, P.R., Holling, C.S., Levin, S., Lindenmayer, D., Pahl-Wostl, C., Possingham, H., Turner, M.G., Westoby, M., 2009. Diversity in current ecological thinking: implications for environmental management. Environmental Management 43, 17–27.

Priest, S.H., Bonfadelli, H., Rusanen, M., 2003. The "trust gap" hypothesis: predicting support for biotechnology across national cultures as a function of trust in actors. Risk Analysis 23, 751–766.

Sapir, E., 1985. Culture, Language and Personality. Selected Essays by Edward Sapir. University of California Press, Berkeley.

Sarewitz, D., 2004. How science makes environmental controversies worse. Environmental Science & Policy 7, 385–403.

Scott, W.R., 1995. Institutions and Organizations. Sage, Newbury Park.

Serageldin, I., 1999. Biotechnology and food security in the 21st century. Science 285, 387–389.

Shackle, G.L., 1955. Uncertainty in Economics and Other Reflections. Cambridge University Press, Cambridge.

Sinemus, K., Egelhofer, M., 2007. Transparent communication strategy on GMOs: will it change public opinion? Biotechnology Journal 2, 1141–1146.

Spash, C.L., 2002. Greenhouse Economics. Values and Ethics. Routledge, London.

Srinivasan, C.S., Thirtle, C., 2003. Potential economic impacts of terminator technologies: policy implications for developing countries. Environment and Development Economics 8, 187–205.

Stirling, A., 1998. Risk at a turning point? Journal of Risk Research 1, 97–109.

Stirling, A., Leach, M., Mehta, L., Scoones, I., Smith, A., Stagl, S., Thompson, J., 2007. Empowering designs: towards more progressive appraisal of sustainability. STEPS

Working Paper 3. STEPS (Social, Technological and Environmental Pathways to Sustainability) Centre, Brighton.

Strand, R., Oughton, D., Mærli, M.B., Myhr, A.I., Hessen, D.O., Kaiser, M., 2009. Risk and uncertainty as a research ethics challenge. Publication no. 9. National Committees for Research Ethics in Norway, Oslo.

Thompson, P.B., 2003. Value judgments and risk comparisons. The case of genetically engineered crops. Plant Physiology 132, 10–16.

UNCTAD, 2006. Tracking the trend towards market concentration: the case of the agricultural input industry. United Nations Conference on Trade and Development. Study prepared by the UNCTAD secretariat. http://www.unctad.org/en/docs/ditccom200516_en.pdf.

Vatn, A., 2005. Institutions and the Environment. Edward Elgar, Cheltenham.

Westrum, R., 1991. Technologies and Society. The Shaping of People and Things. Wadsworth Publishing Company, Belmont.

Wiek, A., Zemp, S., Siegrist, M., Walter, A.I. 2007. Sustainable governance of emerging technologies—critical constellations in the agent network of nanotechnology. Technology in Society 29, 388–406.

Williamson, O.E., 1999. Public and private bureaucracies: a transaction cost economics perspective. The Journal of Law, Economics & Organization 15, 306–342.

Wolfenbarger, L.L., Phifer, P.R., 2000. The ecological risks and benefits of genetically engineered plants. Science 290, 2088–2092.

Whorf, B.L., 1956. Language, Thought, and Reality. MIT Press, Cambridge.

Wynne, B., 1992. Uncertainty and environmental learning: reconceiving science and policy in the preventive paradigm. Global Environmental Change 2, 111–127.

Young, O.R., 2002. The Institutional Dimension of Environmental Change. Fit, Interplay, and Scale. The MIT Press, Cambridge.

# Paper I

# Scientists' Perspectives on the Deliberate Release of GM Crops

VALBORG KVAKKESTAD

*Department of Economics and Resource Management*
*Norwegian University of Life Sciences*
*PO Box 5033, NO-1432 Ås, Norway*

FRØYDIS GILLUND

*Former Master student at*
*Department of Natural Resource Management*
*Norwegian University of Life Sciences*
*PO Box 5033, NO-1432 Ås, Norway*

KAMILLA ANETTE KJØLBERG

*Former Master student at*
*Department of Natural Resource Management*
*Norwegian University of Life Sciences*
*PO Box 5033, NO-1432 Ås, Norway*

AND

ARILD VATN

*Department of Economics and Resource Management*
*Norwegian University of Life Sciences*
*PO Box 5033, NO-1432 Ås, Norway*

## ABSTRACT

In this paper we analyse scientists' perspectives on the release of genetically modified (GM) crops into the environment, and the relationship between their perspectives and the context that they work within, e.g. their place of employment (university or industry), funding of their research (public or industry) and their disciplinary background (ecology, molecular biology or conventional plant breeding). We employed Q-methodology to examine these issues. Two distinct factors were identified by interviewing 62 scientists. These two factors included 92 per cent of the sample. Scientists in factor 1 had a moderately negative attitude to GM crops and emphasised the uncertainty and ignorance involved, while scientists in factor 2 had a positive attitude to GM crops and emphasised that GM crops are useful and do not represent any unique risks

*Environmental Values* **16** (2007): 79–104

compared to conventional crops. Funding had a significant effect on the perspective held by the scientists in this study. No ecologists were associated with factor 2, while all the scientists employed in the GM-industry were associated with this factor. The strong effects of training and funding might justify certain institutional changes concerning how we organise science and how we make public decisions when new technologies are to be evaluated. Policy makers should encourage more interdisciplinary training and research and they should make sure that representatives of different disciplines are involved in public decisions on new technologies.

KEYWORDS

GM crops, ignorance, science, context, values

## INTRODUCTION

Scientists play an important role in the introduction of new technologies. They are often the ones that develop these technologies and the ones that are called as *experts* to evaluate the safety of new technologies. The public is, on the other hand, often portrayed as ignorant and irrational concerning their ability to evaluate new technologies (Cook et al. 2004; Slovic 2001; Wynne 2001). This central position of scientists in the introduction of new technologies makes it important to pay attention to their perspectives on new technologies and contextual factors that may relate to these perspectives. This paper examines scientists' perspectives on a particular technology – genetically modified (GM) crops – and the relationship between their perspective and the context in which the scientists are trained and work.

GM crops are plants whose genetic material has been altered by the direct introduction of DNA in order to confer particular characteristics on the plant. More than 99 per cent of the GM crops grown are varieties of maize, soybean, cotton and oil seed rape and more than 99 per cent of these GM varieties have been engineered to be herbicide tolerant and/or insect resistant (James 2004).

The introduction of GM crops into agriculture has been subject to considerable debate. Concerns have been raised about the potential irreversible impacts of releasing genetically modified organisms (GMOs) into the natural environment (Wolfenbager and Phifer 2000), while others emphasise their potential benefits in increasing agricultural output and enhancing certain aspects of food quality, as well as potential environmental benefits such as reduced pesticide and herbicide use (Conner et al. 2003; James 2002; McGloughlin 1999). Significant participants in this debate have been scientists, industry representatives, environmental organisations and consumer organisations. The general public has also participated.

A growing number of studies shed light on the public's perspectives on GM crops (see for example Bredahl 1999; Gaskell et al. 2000; Grove-White 2001; Marris et al. 2001). Perspectives among scientists are much less studied (Meyer and Sandøe 2001). However, it seems as if scientists hold opposing viewpoints on the deliberate release of GM crops. Busch et al. (2004) emphasise that the GM crop issue is characterised by low consensus with respect to the parameters of the scientific issues and the analytical methods to be applied. This paper focuses on how scientists evaluate the reasonability of releasing GM crops into the environment and how this evaluation is related to their contextual background. We are particularly interested in:

1. What are the perspectives scientists hold on the release of GM crops into the environment?
2. What characterises scientists with the same perspectives on the release of GM crops into the environment?

We have employed Q-methodology and logistic regression to examine these two questions. Sixty-two Scandinavian scientists from different disciplines (molecular biology and related fields,[1] ecology and conventional plant breeding) were interviewed. These disciplines were chosen because they represent perceived expert knowledge concerning the biological impacts of releasing GM crops. The scientists were employed in the university and the industry sector. The scientists working in universities included scientists with purely public funding and scientists with some industry funding.

The paper is organised as follows. We start with two sections where we first identify four dimensions that might be important for scientists when they evaluate the reasonableness of releasing GM crops. Next we analyse how scientists' responses to these dimensions might relate to their contextual background. These two issues are then analysed empirically in the next sections. First we identify different perspectives on the release of GM crops among the scientists in our study by Q-methodology. Next we examine the relationship between the contextual background – like discipline and funding – of the scientists and the perspective they hold on the release of GM crops. The two final sections summarise the findings and discuss the general lessons of these findings.

## IMPORTANT DIMENSIONS FOR SCIENTISTS' EVALUATION OF THE RELEASE OF GM CROPS

Following the debate about GM crops among scientists it seems that there might be four important dimensions for scientists' evaluation: 'the consequences of releasing GM crops', 'our ability to predict the consequences', 'whether GM crops are fundamentally different from conventional crops', as well as 'the moral status of nature'. Diverging responses to these dimensions both in terms of how

they are factually evaluated, but also the importance given to them might partly explain why scientists disagree on the reasonableness of releasing GM crops.

Scientists' evaluation of the release of GM crops into the environment might depend on their beliefs about the consequences of releasing GM crops and their evaluation of these consequences.[2] This involves both factual beliefs about nature and society (what will happen) and value commitments (how consequences are evaluated). Divergence on both of these issues is especially evident concerning the environmental effects of the deliberate release of GM crops as well as their role in decreasing poverty and hunger in developing countries (Pretty 2002).

Scientists' responses to the second dimension, 'our ability to predict the consequences' of releasing GM crops, might also influence their evaluation of the deliberate release of GM crops. The concepts risk, uncertainty and ignorance represent different degrees of predictability. Risk implies known outcomes with known probabilities, while uncertainty means known outcomes but unknown probabilities (Knight 1921). A situation where even the outcomes are unknown is defined as ignorance (Shackle 1955). Ignorance arises from many sources, including 'incomplete knowledge, contradictory information, conceptual imprecision, divergent frames of reference and the intrinsic complexity or indeterminacy of many natural and social processes' (Stirling 1998: 103). The scientists' evaluation of the reasonability of releasing GM crops into the environment is likely to be influenced by whether s/he believes that we are faced with risk, uncertainty or ignorance. If uncertainty and ignorance are recognised, an important issue is also whether the scientists argue that we should take precautionary measures or not.

A further central issue, if uncertainty and ignorance are recognised, is whether they are assumed to be reducible i.e. if they can be reduced by more scientific knowledge (Faber et al. 1996; Wynne 1992). Uncertainty can be perceived to be irreducible due to measurement problems (Spash 2002) and ignorance can be irreducible due to the incompleteness of scientific methods and complexity or indeterminacy in social-ecological processes. An example of a response to assumed reducible ignorance is to emphasise that we have no previous experience on how to predict the impact of GMOs on ecosystems, and so need to accumulate a large and reassuring body of data (Tait and Levidow 1992). An example of a response to assumed irreducible ignorance is to emphasise that the complexity of an ecosystem implies that we never will be able to predict all the effects of releasing GM crops and therefore will need to remain precautionary for the foreseeable future (Tait and Levidow 1992).

Scientists' evaluation of the release of GM crops might also depend on the third dimension 'whether GM crops are fundamentally different from conventional crops'. It has been claimed both that biotechnology offers better control and predictability over nature and that it offers less control and predictability over nature than conventional plant breeding (Krimsky and Wrubel 1996). The central issue is whether the application of gene technology means that there is a

greater chance for surprising adverse effects of GM crops than of conventionally bred crops (National Research Council 2000).

Beliefs about 'the moral status of nature' are likely to influence the evaluation of the release of GM crops since this influences the view on how we can and should interact with nature (Bruce 2003; Carr and Levidow 1997; Nielsen 1997; Regal 1994; Sjöberg 2002; Wagner et al. 2002). One aspect is the differences in perspective that stem from whether the scientist holds an anthropocentric or ecocentric worldview. Given an ecocentric approach, the heart of the debate might be to what extent genetic engineering is perceived to violate the integrity of plants and nature. From an anthropocentric point of view the centre of the discussion might be whether GM crops are seen to benefit mankind or not.

There is a strong relationship between the four dimensions. One example is that assumptions about the predictability of releasing GM crops might influence how scientists evaluate possible consequences. Another example is that views on the moral status of nature might influence whether 'natural' methods or more human-created methods are perceived as most risky (Bruce and Eldrige 2000). A third example is that views on whether GM crops are fundamentally different from conventional crops depend on the moral status of nature as well as assumptions on our ability to predict nature.

## CONTEXTUAL INFLUENCE ON SCIENTISTS' PERSPECTIVES ON GM CROPS

Scientists observe and understand the external world via humanly constructed concepts. The locus of knowledge is the social group of scientists and not the individual scientist (Restivo 1995). Products of science are contextually specific constructions, which are influenced by the situational contingency and interest structure of the process by which they are generated (Knorr-Cetina 1981). We are interested in how the contextual factors disciplinary background, place of employment, research funding and type of research relate to scientists' response to the three first dimensions in the previous section. Other contextual factors are likely to be more important for the response to 'the moral status of nature', but these factors are not examined in this paper.

The disciplines ecology, conventional plant breeding, molecular biology and related fields study different aspects of biological systems and they hold different assumptions on our ability to predict nature. Ecology is a holistic discipline that studies large biological systems over long time spans by looking at organisms and their interactions with each other and the environment (Sterelny and Griffiths 1999). These interactions are mainly studied in the environment where they occur and explanation and descriptions rather than prediction predominate (Krimsky 1991). An important focus is nature's complexity. There are different ways to approach this complexity. Two main, opposing positions can be

identified within the discipline (Pickett et al. 1992; Worster 1990), though most ecologists place themselves somewhere between these two extreme positions. The first position views the 'ecosystem' as a system directed toward achieving as large and diverse an organic structure as possible within its physical limits. The idea is that all natural systems move toward equilibrium by going through successional stages in a certain order. According to this position, any human interference will disturb nature's strategy of development. The second position gives more emphasis to disturbance, disharmony and chaos when studying ecology. Change is without any determinable direction and goes on forever, without ever reaching a point of stability. There is no such thing as equilibrium within this position, which sees nature as fundamentally discontinuous, unpredictable and chaotic. Some ecologists might therefore emphasise that effects of releasing GM crops are unpredictable, others will focus attention towards the fact that genetic engineering might be a costly interference with nature, possibly disturbing balanced ecosystems.

Molecular biology and related fields such as molecular genetics and biochemistry work at the subcellular level with organelles and molecules. The tools known as biotechnology and/or genetic engineering have emerged from these disciplines. The primary concern is the construction and improvement of the theoretical understanding of the molecular mechanisms involved, as well as of experimental and technological laboratory methods, products and practical solutions (Strand 2001). Confidence in human control over biological systems and our predictive capacities as well as reductionism and genetic determinism dominates (Busch et al. 1991; Krimsky 1991; Nielsen 2002; Strohman 1997; Verhoog 1993). The concern is not merely to understand nature, but to control it. The idea is that if we can understand and control the way genes work, we might increase our ability to control and understand nature. Scientists that belong to these disciplines might be expected to emphasise that the application of biotechnology in plant breeding is likely to increase control and predictability and therefore that the application of this technology can benefit mankind and nature.

Today conventional plant breeding is seen as the 'unfashionable older cousin' of genetic engineering (Knight 2003). In many ways this discipline has more in common with molecular biology and related fields than with ecology. The two fields share an emphasis on the control of nature and crop improvement for human needs (Busch et al. 1991). Still, conventional plant breeding differs considerably from molecular biology and related fields, both because conventional plant breeders work largely with whole plants, either as individuals or as large but uniform populations (Krimsky 1982), and because they apply other techniques than genetic engineering. This last property of conventional plant breeding makes it especially interesting to study their perspective on GM crops. Conventional plant breeders may hold a different perspective from molecular biologists on whether GM crops are fundamentally different from conventional crops.

An interesting question is whether place of employment, i.e. whether the scientists are employed in the university or the industry sector, might be related to their perspective on GM crops. Scientists employed by industry have a duty to serve the interests of its shareholders (Stone 2002). Industry research is therefore directed by an obligation to make profit. This implies incentives for producing knowledge that can result in valuable products. Topics and issues that are external to the market place become less important under industry research. The incentives under public employment are less clear. The idealised account of public science is that it should be based on a dialectic approach between intellectual inquiry and public need (Caldart 1983). However, this idealised account is found not to be an adequate description of science (Mulkay 1979).

It is increasingly being argued that the research culture within universities has become more similar to that of industry and that this development has gone particularly far within areas such as plant biotechnology (Gibbons 1999). University research has become more market oriented, partly through increased industry funding (Newberg and Dunn 2002). Hence, it becomes useful to distinguish not only between scientists employed within industry and universities, but also between university scientists that have industry funding and those who do not. Industry funded scientists are likely to hold a perspective that serves the interests of the shareholders. This implies that they are likely to emphasise the positive aspects of GM crops to create a positive public opinion on GM crops, but at the same time they have to secure that no products that could harm the reputation of their company enter the market. Publicly funded scientists are unlikely to have any homogenous perspective on the deliberate release of GM crops.

Type of research in terms of whether the scientists undertake risk research, basic or product research might also relate to their perspective on GM crops. Scientists that undertake risk research are likely to pay attention to the risks, while scientists that are involved in product research are likely to pay more attention to the useful attributes of GM crops when they evaluate the reasonability of GM crops.

## METHODOLOGY

Perspectives on the deliberate release of GM crops among scientists were assessed through Q methodology. Q methodology is a type of discourse analysis that enables the identification of common patterns of opinion held by a certain group of people (Addams and Proops 2000; Barry and Proops 1999; Brown 1980). Respondents are asked to sort a given number of statements, in relation to each other, according to an evaluative profile ranging from agree to disagree. This data is then factor analysed to identify patterns of communality and divergence in expressed viewpoints, i.e. typical discourses or perspectives among the respondents. The basic distinctiveness of Q methodology is that, unlike standard

survey analysis, it is interested in establishing patterns within and across individuals rather than patterns across individual traits, such as gender, age etc.

Q-methodology includes the following stages: 1) Selection of statements which 2) participants are asked to rank. This set of ranked statements constitutes the 'Q sort' for each participant. 3) From these Q sorts factor analysis allows the extraction of a few factors and 4) the generation of a single typical or ideal Q sorts for each factor. 5) A qualitative analysis is conducted of these ideal Q-sorts.

In our study a series of 245 statements were obtained from interviews with scientists, and from reports, books, webpages and peer-reviewed articles. The goal was to achieve a rich diversity of statement types which existed in the scientific discourses on GM crops. A final number of 36 statements were chosen based on the result of pilot-testing with scientists. The 36 statements are included in table 2.

The second step – the ranking of the 36 statements by each participant – was administered through personal interviews with 62 Scandinavian scientists. As a starting point a group of nearly 70 scientists was identified by contacting different universities, public research institutes and firms. Some of these scientists did not participate because they did not respond to e-mails or phone calls or because it was not practically feasible to interview them. Respondents were asked to rank the 36 statements in a forced normal distribution along the scale of strongly agree (5) to strongly disagree (-5) as shown in table 1.

TABLE 1. Distribution of 36 statements in a Q sort on a scale from strongly disagree (-5) to strongly agree (5)

| Strongly disagree | -5 | -4 | -3 | -2 | -1 | 0 | 1 | 2 | 3 | 4 | 5 | Strongly agree |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | -5 | -4 | -3 | -2 | -1 | 0 | 1 | 2 | 3 | 4 | 5 | |
| | | -4 | -3 | -2 | -1 | 0 | 1 | 2 | 3 | 4 | | |
| | | | -3 | -2 | -1 | 0 | 1 | 2 | 3 | | | |
| | | | | -2 | -1 | 0 | 1 | 2 | | | | |
| | | | | | -1 | 0 | 1 | | | | | |
| | | | | | | 0 | | | | | | |

The third step – the factor analysis of the 62 individual rankings (Q sorts) – was undertaken by principal components factor analysis with varimax rotation. This procedure resulted in the extraction of a few factors. The number of factors extracted was based on three criteria: 1) the factor should have an eigenvalue greater than one, 2) the number of factors extracted should depend on the point where the eigenvalues begin to level off in a scree plot, which graphs the eigenvalue against the factor number, and 3) the factors should be theoretically important and reveal distinct and coherent views. Factor loadings (correlation coefficients) that indicate the degree to which each Q sort correlates with each extracted factor

were generated. A significant[3] factor loading is one which is sufficiently high to assume that a relation exists between the respondent and the factor.

The fourth step was to generate a single 'ideal' Q sort and thereby also factor rankings[4] for each factor by merging, according to a procedure of weighted averaging, the rankings of the scientists that loaded significantly on the respective factor (Brown 1980). More weight was given to the rankings of participants who had higher factor loadings, since they were more representative of the factor type. Hence, emergent ideal Q sorts do not represent the viewpoint of any given individual, but the shared patterns within the pooled data. The 'ideal' Q sorts are termed 'perspectives' in this paper.

The final step was the process of factor interpretation by developing a plausible explanation of the factor rankings of each factor. The statement had to be interpreted in relation to the other statements since the Q-sorts represents relative ranking of statements.

The personal interviews involved other elements than ranking the statements. The participants were asked to explain the positioning of the three most agreed/disagreed statements and to comment on the selection of statements as well as how well their Q sorts expressed their perspective on the deliberate release of GM crops. Participants also completed a questionnaire about their age, gender, discipline, place of employment, external funding of their research, whether they were doing basic, applied or risk research, as well as their general attitude to GM crops.

## SCIENTISTS' PERSPECTIVES ON GM CROPS

This section presents the results from employing Q methodology to assess the perspectives held by scientists on GM crops. First we present the results of the factor analysis. Next we present the factor rankings of the extracted factors. Finally we interpret the factor rankings.

### *Factor analysis*

The factor analysis yielded 13 factors with eigenvalues greater than 1. However, only three factors were extracted as the use of a scree plot indicated a natural break in the sizes of eigenvalues when three factors were extracted. The three factors accounted for 55 percent of the variance of the rotated correlation matrix. 32 participants loaded significantly on factor 1, 25 participants loaded significantly on factor 2 and one participant loaded significantly on factor 3. The last factor[5] was not accepted since there were less than two Q sorts loading significantly on it.[6] Both remaining factors were theoretically important and revealed distinct and coherent views. We also ran two separate Q sort factor analyses to explore the diversity of viewpoints among the participants that loaded significantly

on each of the two factors. These two factor analyses did not add much new information to the information already gained from the first factor analysis and are therefore not included in this paper.

*Factor rankings*

Table 2 presents the factor rankings of the 36 statements for factor 1 and 2.

TABLE 2. Q-sort statements and their factor rankings

| Statement | Factor rankings | |
|---|---|---|
| | 1[1] | 2[2] |
| 1. The use of GM-crops in agricultural production is unnecessary. | 0 | -4 |
| 2. Gene technology will contribute to the achievement of a sustainable agriculture. | -1 | 4 |
| 3. It is unethical to deny the exploration of gene technology since it may play an important role in future food security for the world's population. | 0 | 4 |
| 4. The ability to break species' boundaries is a strongly negative feature of gene technology independent of whether GM-crops represent unique risks. | 0 | -5 |
| 5. Genetic modification is a natural process since horizontal gene flow between sexually incompatible species occurs regularly in nature. | -1 | 0 |
| 6. The environmental issues raised by growing currently available GM-crops do not differ qualitatively from conventional crops, therefore the characteristics of each crop variety must be evaluated, not the specific plant breeding method used. | -1 | 5 |
| 7. Potential unanticipated effects from GM-crops might arise from the capability of transferring genes into very different genetic backgrounds. | 2 | 0 |
| 8. Genetic engineering increases the degree of control and predictability regarding the traits expressed by the new variety compared to other methods applied in conventional plant breeding. | -2 | 3 |
| 9. An important uncertainty is how farmers apply the GM technology in the field. | 1 | 0 |
| 10. I have little confidence in the gene technology research undertaken by industry since it is highly influenced by commercial interests. | 3 | -4 |
| 11. Scientific knowledge is not and never will be sufficient to predict future impacts of GM-crops. | 1 | -2 |
| 12. Our present scientific knowledge is not sufficient to evaluate the environmental safety of GM- crops today. | 4 | -3 |
| 13. GM-crops are safe because no one has shown that significant environmental damage has occurred following cultivation of GM-crops. | -4 | -1 |
| 14. The lessons of history tell us that new technologies bring new unknowns and that we sometimes have rushed forward to exploit new technologies, only subsequently to discover the environmental costs. It is likely that this will happen with GM-crops, unless we take precautionary measures. | 3 | -1 |
| 15. Standardised quantitative methods need to be the primary basis for assessing the environmental impacts of GM-crops. | 1 | 3 |

| | | |
|---|---|---|
| 16. It is impossible to quantify the ecological impacts of growing GM-crops. | 1 | -1 |
| 17. It is important to take unforeseen consequences into consideration when evaluating the release of GM-crops into the environment. | 4 | 2 |
| 18. The consequences of a GM-based agriculture have to be compared with the consequences of organic agriculture. | 0 | 1 |
| 19. Lay people are sceptical to GM-crops because they lack knowledge about the technology. | 0 | 1 |
| 20. We live in a risk-society and have to accept that technologies, like genetic engineering, with the risk of unlikely but very negative consequences are part of our life. | -2 | 0 |
| 21. Risk and uncertainty regarding ecological effects in natural habitats should not prevent the use of GM-crops in agriculture if these have documented positive effect on productivity and result in reduced use of pesticides. | -2 | 1 |
| 22. GM- traits that enhance resistance to certain herbicides benefit the environment by decreasing the need for chemicals. | -1 | 2 |
| 23. The use of insect resistant GM-crops, such as the different Bt varieties, will enhance the development of resistance among target pest species. | 2 | 1 |
| 24. The instability of the transferred gene is of key concern. | 2 | -3 |
| 25. We cannot take into consideration the theoretically possible, but extremely unlikely event of severe reduction in the population of pollinators into consideration when considering the release of a GM-crop. | -2 | -2 |
| 26. The unintended spread of herbicide resistance from genetically modified crops to weeds and other plant life is likely to raise concerns for the structure and function of ecosystems. | 2 | -3 |
| 27. The potential effects of Bt-crops on non-target organisms are expected to be less severe than the potential effects of broad-spectrum insecticides on non-target organisms. | -1 | 3 |
| 28. We have the same ability to predict ecological changes from both GM-crops and conventional crops. | -3 | 2 |
| 29. Any negative environmental consequences that may arise from growing GM-crops will be adequately addressed by future developments in genetic engineering or other technologies. | -3 | 0 |
| 30. The possible negative impacts of GM-crops on biodiversity are likely to be reversible. | -3 | 0 |
| 31. The really serious problems with GM-crops may arise only slowly, subtly and through long chains of events. | 3 | -1 |
| 32. I see no danger whatsoever of releasing GM-crops into the environment, because of the stability and resilience of ecosystems. | -5 | -2 |
| 33. Many ecosystem interactions are so complex that the risk of modern biotechnology is unpredictable. | 5 | -1 |
| 34. Results from laboratory experiments on GM-crops can be, in most cases, directly transferred to natural conditions. | -4 | -2 |
| 35. Man has an obligation to use the possibilities embedded in nature for the betterment of mankind. | 0 | 2 |
| 36. Nature possesses an intrinsic value that is independent of human needs. | 1 | 1 |

[1]Factor 1, [2] Factor 2

*Factor interpretation*

*Perspective 1: 'The environmental effects are unpredictable'*

Factor 1 exemplars[7] strongly emphasise the unpredictability of the environmental effects from GM crops. Ecosystems are complex (33:5)[8] and our present scientific knowledge is insufficient (12:4). Major long-term unanticipated impacts might arise (14:3; 31:3). However, factor 1 exemplars have no strong opinion on whether we are faced with irreducible ignorance (16:1; 11:1). They emphasise that results from laboratory experiments on GM crops can not be directly transferred to natural conditions (34:-4) and they have little confidence in research undertaken by industry (10:3).

Factor 1 exemplars have no strong opinion on the claimed beneficial effects of GM crops (3:0; 2:-1; 27:-1; 22:-1), while they emphasise that the unintended spread of herbicide resistance from GM crops is likely to raise concern for ecosystems (26:2). The possible negative impacts are likely to be irreversible (29:-3; 30:-3).

They appear neutral on whether the ability to break species' boundaries is a negative feature of gene technology (4:0) or whether the environmental issues raised by growing GM crops differ from conventional crops (6:-1). However, they emphasise that potential unanticipated effects might arise from the capability of transferring genes into very different backgrounds (7:2) and that effects from GM crops are more unpredictable than effects from conventional crops (28:-3; 8:-2).

**Box 1: Characteristics of perspective 1**

Factor 1 exemplars strongly emphasise the unpredictability of the environmental effects from GM crops, while they have no strong opinion on claimed positive consequences of GM crops and whether GM crops are fundamentally different from conventional crops. The presence of negative consequences of growing GM crops is moderately emphasised. This means that less emphasis is put on known possible harmful effects than on unpredictability. They have little confidence in gene technology research undertaken by industry.

*Perspective 2: 'GM crops present no unique risks and are useful'*

Factor 2 exemplars strongly emphasise that the ability to break species' boundaries is not a negative feature of gene technology (4:-5)[9] and that the environmental issues raised by growing GM crops do not differ from conventional crops (6: 5). We have the same ability to predict ecological changes from GM crops and conventional corps (28:2) and genetic engineering increases the control and predictability of the expressed traits compared to conventional plant breeding (8:3).

The use of GM crops in agriculture is considered necessary (1:-4). This is partly explained by the role that GM crops might play for increased food secu-

rity (3:4), sustainable agriculture (2:4), and reduced pesticide use (27:3; 22:2). The unintended spread of herbicide resistance from GM crops is not likely to raise concern for the structure and function of ecosystems (26;-3). Scientists in factor 2 appear neutral on whether the use of Bt-crops will enhance resistance among target species (23:1) and whether the negative impacts of GM crops will be reversible (30:0; 29:0).

In general, scientists in factor 2 appear neutral on aspects regarding the predictability of GM crops (33:-1; 7:0; 31:-1; 14:-1; 16:-1; 13:-1) However, they emphasise that it is important to take unforeseen consequences into consideration when evaluating the release of GM crops (17:2). They disagree that scientific knowledge is not (12:-3), and never will be, sufficient to predict impacts of GM crops (11:-2). Further aspects of factor 2 exemplars are their confidence in gene technology research undertaken by industry (10:-4) and that they emphasise that man has an obligation to use the possibilities embedded in nature for the betterment of mankind (35:2).

**Box 2: Characteristics of perspective 2**

Factor 2 exemplars strongly emphasise that GM crops are not fundamentally different from conventional crops and that these crops are likely to have major positive consequences. They have no strong opinion on the predictability of the environmental effects from GM crops or on potential negative impacts from growing GM crops. They have confidence in gene technology research undertaken by industry.

*Areas of agreement and disagreement among perspective 1 and 2*

One of the main tendencies in our findings is that factor 1 and 2 exemplars rarely have opposing views on the same issues; rather, they feel strongly about different issues.[10] Examples are positive consequences of GM crops (3:0,4; 2:-1,4; 27:-1,3; 1:0,-4),[11] whether potential negative impacts are likely to be reversible (29:-3,0; 30-3,0), whether ecosystem interactions are so complex that the risk of modern biotechnology is unpredictable (33:5,-1), the possibility for major long-term unanticipated impacts (14:3,-1; 31:3,-1), whether the ability to break species' boundaries is a negative feature of gene technology (4:0,-5), whether the environmental issues raised by growing GM crops differs from conventional crops (6:-1,5), and whether GM crops are safe because no one has shown any significant environmental damages (13:-4,-1).

The major areas of disagreement among the two factor groups are whether present scientific knowledge is insufficient to assess the environmental safety of GM crops (12:4,-3), whether the spread of herbicide resistance from GM crops is likely to raise concern for ecosystems (26:2,-3), whether genetic engineering increases control and predictability (8:-2,3; 28:-3,2), and whether industry funded gene technology research is influenced by commercial interests (10: 3,-4).

The scientists have no strong opinion on most of the issues that they agree on. Neither of the groups have strong opinions on whether nature possesses an intrinsic value (36:1,1), whether lay people are sceptical to GM crops because they lack knowledge about the technology (19:0,1), whether how farmers apply the GM-technology is an important uncertainty (9:1,0), and whether it is impossible to quantify the ecological impacts of growing GM crops (16:1,-1). They also agree that the use of Bt-crops will enhance the development of resistance among target species (23:2,1).

## CHARACTERISTICS OF SCIENTISTS WITH THE SAME PERSPECTIVE ON GM CROPS

Having identified different perspectives on GM crops, an important question is what characterises scientists that hold the same perspective. We have addressed this issue by analysing whether the scientists' general attitude to GM crops and their contextual background (discipline, funding, type of research, place of employment) is linked to significant loading on factor 1 and 2, i.e. whether they hold perspective 1 or 2. These two perspectives cannot be considered to be the only two ways scientists think about GM crops. However, the two perspectives point out basic differences among the participating scientists' perspectives on GM crops. Examining the characteristics of the scientists in each factor group can suggest reasons why they hold different perspectives on GM crops.

The scientists were asked to indicate their general attitude to GM crops on a scale ranging from 1 to 5, where 1 is negative and 5 is positive. A logistic regression model was then developed to analyse the relationship between the scientists' general attitude to GM crops and the perspective they hold. Table 3 presents the attitudes of the scientists that loaded significantly on the two factors and the results from the logistic regression model.

TABLE 3. Descriptive statistics for attitude[1] to GM crops, and parameter estimates and Wald statistics of a logistic regression model predicting perspective on GM crops by attitude to GM crops (n=56[2])

| | Factor | | Logistic regression model[3] | |
|---|---|---|---|---|
| | 1 | 2 | β | $Z^2$ |
| Mean attitude | 2,7 | 4,7 | -2,8 | 15,7* |
| Std | 1,0 | 0,5 | | |

[1]Measured on a five point Lickert scale (1:negative, 5: positive)

[2]One of the respondents that loaded significantly on factor 1 is excluded from the sample because of negative correlation coefficient.

[3]y=1 if perspective 1, and 0 if perspective 2

*p<0,0001

All of the factor 2 exemplars are very positive to GM crops, while factor 1 exemplars are moderately negative. There is a substantial variation in attitude among the factor 1 exemplars, while this is not the case for factor 2 exemplars. Logistic regression predicting significant loading on factor 1 by attitude to GM crops indicates that general attitude to GM crops has a significant effect on the perspective they hold on GM crops. The more negative the scientists are, the more likely is it that they hold perspective 1.

To analyse whether the scientists' contextual background is related to significant loading on factor 1 and 2, we wanted to develop a logistic regression model that included the explanatory dummy variables funding, discipline, type of research and place of employment, as well as interaction effects between these variables to predict perspectives on GM crops. However, for several of the intended explanatory variables some categories were missing. Ecologists and industry-employed scientists were for example only present in one of the perspectives. It is not possible to include explanatory dummy variables in a logistic regression model if some categories are missing and it was therefore not possible to develop one logistic regression model with all the intended variables. We have therefore analysed the relationship between the contextual background of the scientists and significant loading on factor 1 and 2 by three steps. First we present the background characteristics of the scientists in each of the two perspectives and analyse the association between these background characteristics and perspective on GM crops by chi-square tests (see table 4). Then we present the results from three different logistic regression models that include different explanatory variables and different groups of the scientists (see table 5). Finally we present the interaction effects (see table 6). The control variables age and gender had no significant effect and are therefore not included in the analysis.

Table 4 shows a very clear pattern; no ecologists, and no scientists employed in the foundation (a non-commercial foundation that is located in a research environment) or the conventional plant breeding company are associated with perspective 2, while all the scientists employed in the GM-industry are associated with perspective 2. Most of the scientists that belong to other disciplines (agrobiology, plant physiology, evolutionary genetics and bio-ethics) hold perspective 1. Chi-square tests suggest that perspective on GM crops depends on discipline, place of employment, funding and type of research.

Table 5 presents the parameter estimates and their Wald statistics for three logistic regression models that include different explanatory variables and different groups of the scientists that loaded significantly on factor 1 or 2. The three models were developed since these were the models that satisfied the requirement that no categories in an explanatory dummy variable should be missing, i.e. funding was included since industry funded scientists and publicly funded scientists hold both perspectives, while place of employment was not included as no industry employed scientists hold perspective 1.

TABLE 4. Characteristics of scientists that hold the same perspectives on GM crops, and chi-square tests for independence between perspective on GM crops and discipline, place of employment, funding and type of research

| | No. of factor 1 exemplars | No. of factor 2 exemplars | $\chi^2$ |
|---|---|---|---|
| Number of scientists | 31 | 25 | |
| Discipline | | | 19,5***[1] |
| Conventional plant breeding | 4 | 2 | |
| Molecular biology & related fields[2] | 8 | 22 | |
| Ecology | 13 | 0 | |
| Other[3] | 6 | 1 | |
| Place of employment | | | 12,1**[4] |
| Foundation[5] | 6 | 0 | |
| University | 21 | 14 | |
| Conventional plant breeding company[6] | 4 | 0 | |
| GM-Industry | 0 | 11 | |
| Funding | | | 24,2*** |
| Public[7] | 30 | 9 | |
| Some/all from GM-industry | 1 | 16 | |
| Type of research | | | 10,8* |
| Risk research | 7 | 1 | |
| Basic research | 18 | 9 | |
| Product research | 6 | 15 | |

[1]'other' and 'conventional plant breeding' are excluded from the tests to ensure expected cell count greater or equal to 5.

[2] Related fields are molecular genetics and biochemistry

[3]'Other' refers to three agrobiologists (one of them loaded significantly on factor 2), two plant physiologists, one evolutionary geneticist, and one scientists who had a background in molecular biology, but is currently working within the field of bio-ethics.

[4]'foundation', and 'conventional plant breeding company' are excluded from the tests to ensure expected cell count greater or equal to 5.

[5]'Foundation' refers to a non-commercial foundation that is located in a research environment.

[6]The conventional plant breeding company is owned by the state, agricultural cooperatives and private companies.

[7] The scientists that work in the conventional plant breeding company are classified as receiving public funding since the majority of their funding is public and since their private funding comes from other sources than the GM-industry. These private funding sources are not likely to relate to their perspective on GM crops in any particular direction since they are not involved in gene technology.

*p<0,005, **p<0,001, ***p<0,0001

TABLE 5. Parameter estimates and Wald statistics of logistic regression models predicting perspective on GM crops (y=1 if perspective 1, and 0 if perspective 2)

| Explanatory variables | Model 1. n=56 | | Model 2. n=43 (no ecologists) | | Model 3. n=30 (only mol. biologists) | |
|---|---|---|---|---|---|---|
| | β | $Z^2$ | β | $Z^2$ | β | $Z^2$ |
| Discipline[1]: Ot | – | – | 2,9 | 4,3* | – | – |
| Discipline[1]: Co | – | – | 0,7 | 0,4 | – | – |
| Funding[2] | 3,9 | 10,2** | 4,1 | 7,0** | 2,7 | 5,4* |
| Type of research: Ri[3] | 2,3 | 2,2 | 1,2 | 0,6 | – | – |
| Type of research: Ba[3] | 0,3 | 0,1 | -1,5 | 1,8 | – | – |

[1] Measured as two dummy variables 'Ot' and 'Co' where in the case of Ot 1 denotes other (agrobiology, plant physiology, evolutionary geneticist, and bio-ethics) and 0 denotes otherwise, and where in the case of Co 1 denotes conventional plant breeding and 0 denotes otherwise.

[2] Measured as a dummy variable where 1 denotes purely publicly funded and 0 denotes otherwise (some/purely industry funded).

[3] Measured as two dummy variables 'Ri' and 'Ba' where in the case of Ri 1 denotes risk research and 0 denotes otherwise, and where in the case of Ba 1 denotes basic research and 0 denotes otherwise.

*p<0,05, **p<0,01

Model 1 in table 5 includes all the 56 factor 1 and factor 2 scientists and examines the relationship between perspective on GM crops, funding and type of research. The model predicts that scientists who are publicly funded are more likely to hold perspective 1 than scientists that are partly or purely industry funded. Type of research has no significant effect.

Discipline could not be included in model 1 as no ecologists hold perspective 2. However, by excluding the ecologists from the model, we could include discipline as an explanatory variable as the other disciplinary categories are present in both perspectives. This is what we have done in model 2. The results are similar to those in model 1 in terms that funding has significant effect, while type of research has no significant effect. Whether the discipline is conventional plant breeding or otherwise has no significant effect, while whether the discipline is 'other' (agrobiology, plant physiology, evolutionary geneticist and bio-ethics) or otherwise (molecular biology and conventional plant breeding) has significant effect. Scientists from the disciplinary category 'other' are more likely to hold perspective 1 than conventional plant breeders and molecular biologists.

Model 3 in table 5 only includes the molecular biologists. Funding has significant effect on the perspectives molecular biologists hold on GM crops. Molecular biologists who are partly or purely industry funded are very likely to hold perspective 2, while publicly funded molecular biologists are as likely to hold perspective 1 as perspective 2.

It was not possible to include interaction variables in any of the three models because some of the categories were present in only one of the perspectives. We have therefore presented interaction effects from discipline, funding, place of employment and type of research in table 6.

We see from table 6 that the only category of molecular biologists where the majority hold perspective 1 is molecular biologists that at the same time are employed in the foundation, are doing risk research and are publicly funded. In fact, all the publicly funded scientists that are doing risk research are associated with perspective 1, while the only industry-funded scientist that is doing risk research is associated with perspective 2. Half of the publicly funded molecular biologists are associated with perspective 2, while more than 90 per cent

TABLE 6. Interaction effect from discipline, funding and type of research on perspective on GM crops

| Discipline | Funding | Research | Place of employment | No. of factor 1 exemplars | No. of factor 2 exemplars |
|---|---|---|---|---|---|
| Ecology | Public | Basic | University | 11 | 0 |
| Ecology | Public | Risk | University | 1 | 0 |
| Ecology | Public | Risk | Foundation | 1 | 0 |
| Molecular biology & related fields | Public | Basic | University | 2 | 4 |
| Molecular biology & related fields | Public | Risk | Foundation | 4 | 0 |
| Molecular biology & related fields | Public | Product | University | 1 | 3 |
| Molecular biology & related fields | Some/all from GM-industry | Basic | University | 0 | 3 |
| Molecular biology & related fields | Some/all from GM-industry | Product | University | 1 | 2 |
| Molecular biology & related fields | Some/all from GM-industry | Product | Industry | 0 | 10 |
| Conventional plant breeding | Public | Basic | University | 0 | 2 |
| Conventional plant breeding | Public | Product | Conv. plant breed. comp. | 4 | 0 |
| Other (bioethics)[1] | Public | Risk | Foundation | 1 | 0 |
| Other (plant physiology, agrobiology, evolutionary genetics) | Public | Basic | University | 5 | 0 |
| Other (agrobiology) | Some/all from GM- industry | Risk | Industry | 0 | 1 |
| Total no. of scientists | | | | 31 | 25 |

[1] This scientist had a background in molecular biology

of the partly/purely industry funded molecular biologists are associated with the same perspective. No conventional plant breeders that are employed in the conventional plant breeding company are associated with perspective 2, while no conventional plant breeders that are employed in universities are associated with perspective 1.

## DISCUSSION

In our discussion of the findings, we will first look at the importance of the four dimensions 'the consequences of releasing GM crops', 'our ability to predict the consequences', 'whether GM crops are fundamentally different from conventional crops', and 'the moral status of nature' for the two perspectives on GM crops identified in this study. Next we discuss the importance of discipline, funding, place of employment and type or research for scientists' perspectives on GM crops. Finally, we situate the study in the broader context of debates about science, innovation and value and we examine the implications of this study for these debates.

As emphasised above, factor 1 and factor 2 exemplars generally do not have opposing responses on the same dimensions. Rather they feel strongly about different aspects. The dimension 'our ability to predict the consequences of releasing GM crops' is the most important dimension for the scientists in factor 1 in the sense that they emphasise that consequences are unpredictable. Factor 2 exemplars, on the other hand, have no strong opinion on this issue. Neither factor 1 nor 2 exemplars have any strong opinion concerning whether we are faced with irreducible ignorance or not. The dimensions that concern consequences of releasing GM crops and whether GM crops are fundamentally different from conventional crops are the most important dimensions for scientists in factor 2, while these two dimensions are not so important for scientists in factor 1. Factor 2 exemplars strongly emphasise that GM crops present no unique risks and that GM crops are useful, while they have no strong opinion on negative consequences. Factor 1 exemplars moderately emphasise the presence of negative consequences and have no strong opinion on positive consequences. The dimension 'moral status of nature' is of little importance for both groups of scientists in terms that they have no strong opinion on whether we should hold an anthropocentric or ecocentric position.

The contextual characteristics of the scientists revealed a very clear pattern concerning the perspective they hold on GM crops. All the scientists that were employed in the foundation and in the conventional plant breeding company hold perspective 1, while all the industry-employed scientists hold perspective 2. This might indicate that perspective on GM crops is an important aspect in the recruitment process in these organisations, and/or that the socialisation that takes place in these organisations shapes the perspective on GM crops.

The foundation was created to secure an independent research milieu being independent both of the industry and university priorities. This might partly explain why scientists in this group are so homogenous in their perspective on GM crops. The conventional plant breeding company is recently privatised and the scientists emphasised that they perceived themselves as publicly employed scientists. University scientists are associated with both perspectives. This might indicate that being employed in universities has in itself little influence on scientists' perspectives on GM crops.

Funding has a significant effect on the perspective the scientists hold. Scientists that have some industry funding or are purely industry funded are very likely to be associated with perspective 2, while publicly funded scientists are somewhat more likely to hold perspective 1 than perspective 2. Scientists that are funded by the industry might feel an obligation to serve the interests of the shareholders, while publicly funded scientists possibly take a more autonomous role. Industry funding imposes a one-sided focus on the profits in the near future. Aspects of biological systems that are external to the market as well as long-term effects become irrelevant for their research. It is interesting that industry funded scientists are likely to hold one particular perspective, and that this perspective emphasises that gene technology research undertaken by industry is not influenced by commercial interests.

The fact that all the industry employed scientists hold perspectives 2 and that scientists that have some industry funding are very likely to hold perspective 2 might justify the concerns that have been raised about the commercialisation of GM crop research from the 1980s (see for example Caldart 1983; Newberg and Dunn 2002; Pistorius and Wijk 1999; Stone 2002; Victor and Runge 2002). When formulating policies for GM crop research, the governmental authorities ought to consider that industry funding of GM crop research might influence the perspectives scientists hold and/or that mainly scientists that hold certain perspectives are recruited to GM crops research that are industry funded. Governments should consider reversing the industrial dominance in GM crop research by changing policies for intellectual property rights and public research budgets.

None of the ecologists hold perspective 2, while about three-fourths of the molecular biologists hold perspective 2 and two-thirds of the conventional plant breeders hold perspective 1. It was expected that the ecologists could hold a perspective similar to perspective 1 and that most of the molecular biologists could hold a perspective similar to perspective 2. However, quite a few of the molecular biologists hold perspective 1. Half of the molecular biologists that hold perspective 1 are publicly funded, employed in the foundation and do risk research. These molecular biologists might hold a diverging perspective from most of the other molecular biologists because they work in a different context and/or because it is mainly molecular biologists that emphasise complexity and uncertainty that are recruited to this kind of research. All the conventional plant breeders that are employed in the conventional plant breeding company hold

perspective 1, while all the conventional plant breeders that work in universities hold perspective 2. One of many possible explanations might be that the university employed conventional plant breeders have much contact with molecular biologists, while this is not the case for those working in the company. A reasonable policy response to these results might be to encourage more interdisciplinary training and research. It is also crucial that the policy makers include several disciplines when they ask for scientific advice on policies for GM crops.

The results from this study are of relevance for the wider debate about science, innovation and value that is increasingly taking place in western countries. During the last decades, science has dominantly been valued for its importance for securing economic growth. Wilsdon et al. (2005) emphasise that instead the public value of science, i.e. the total benefits that flow from public science policy, should be the main measure for the value of science and technology. They suggest upstream public engagement as one way to enhance the public value of science. Stakeholders, scientists and the wider public should deliberate on the visions, ends and purposes of science and they should together influence the trajectories of scientific and technological developments. However, the idea about upstream public engagement in science has generated debate. It has been argued that science is not a democratic activity – the accuracy of scientific 'facts' cannot be decided by referenda – and that the public lack the technical insight necessary to contribute.

The results from this study justify upstream public engagement as they illustrate that both factual judgements as well as value judgements are important for scientists' perspectives on GM crops. The existence of uncertainty and ignorance as such implies that value judgments have to be made, as it is not given how one should respond to uncertainty and ignorance. Scientists are not more qualified for making value judgments than others and these judgments should therefore not be left for scientists alone. However, public engagement is not unproblematic. There are several related challenges, like representativeness and accountability, which one needs to be aware of. Decisions on what research might be most valuable will always be based partly on factual assumptions. At least, in some respect, scientists are likely to be more competent on making these assumptions than others.

Wilsdon et al. (2005) also argue that the structures that surround scientists to a greater extent should encourage scientists to be concerned about the public value of science. Our results show that industry funding might impose limits on scientists' possibilities to reflect on the social dimension of their work or at least that the recruitment process is biased and thereby indirectly influences the reflection that will take place.

Dialogue between different types of scientists is important to secure the public value of science, and should be promoted and rewarded according to Wilsdon et al. (2005). The differences in the perspectives held by the scientists in this study justify the fostering of dialogue between scientists. However, an

open-minded dialogue might be difficult to facilitate, as there seems to be a lack of trust between the different groups.

## CONCLUSION

The GM crop issue is characterised by low consensus among scientists. This study has revealed two distinct and independently coherent perspectives on GM crops. Perspective 1 emphasise that the environmental effects from releasing GM crops are unpredictable, while perspective 2 emphasise that GM crops are useful and present no unique risks. No ecologists are associated with perspective 2, while all the scientists employed in the GM-industry are associated with perspective 2. Publicly funded scientists are likely to hold perspective 1, while scientists that are funded by the GM-industry are very likely to hold perspective 2.

An immediate response might be that this study undermines the authority of science. This is not our conclusion. Rather the results might justify certain institutional changes concerning how we organise science and how we make public decisions on new technologies, in order to increase the public value of science. Policy makers should encourage more interdisciplinary training and research, and they should consider to reverse the commercialisation of GM crop research to secure that a substantial part of this research is independent from the priorities of the industry and to a greater extent could serve public needs. The results stress the need for involving scientists from several disciplines in public decisions on new technologies. Information about the contextual background of the scientists is relevant in these decisions as we observe that scientists from different contexts interpret the same information differently. The fact that several value judgments are involved in these decisions might justify public engagement. However, it is also important to emphasise that public participation does not automatically solve the problem of fairness and legitimacy in decision-making. Finally, openness and acceptance to the fact that scientists are also human beings with values could provide the basis for new forms of dialogue between the scientific world and the wider public.

## NOTES

[1] By related fields we mean molecular genetics and biochemistry.

[2] Ajzen and Fishbein (1980) emphasise that attitudes are influenced by the beliefs about the consequences of the behaviour weighted against the evaluation of these consequences.

[3] We have used three criteria for determining significance: 1) the factor loading should exceed 2,58 divided by the square root of the number of statements, 2) squared factor loading on a factor should exceed $h^2/2$, where h (communalities) is the sum of the

squared factor loadings for all the significant factors, 3) criteria 1) and 2) should only show significance for one factor.

[4] The factor rankings related to a factor constitutes the ideal Q sort of that factor.

[5] This factor is characterised by emphasis on the existence of positive and negative consequences of growing GM crops and that GM crops are not fundamentally different from conventional crops. Low confidence in research undertaken by the industry is also emphasised.

[6] It is normal procedure to ignore factors for this reason.

[7] Q sorts which load significantly upon one factor alone are called 'factor exemplars'.

[8] The numbers in parentheses refer to the statement number followed by the factor ranking associated with factor 1.

[9] The numbers in parentheses refer to the statement number followed by the factor ranking associated with factor 2.

[10]Wilkins et al. (2001) present similar findings.

[11] The numbers in parentheses refer to the statement number followed by the factor rankings for that statement in the order of factors (1,2).

## REFERENCES

Addams, H. and J. Proops. 2000. *Social Discourses and Environmental Policy: An application of Q methodology.* Cheltenham: Edward Elgar.

Ajzen, I. and M. Fishbein. 1980. *Understanding Attitudes and Predicting Social Behaviour.* New Jersey: Englewood Cliffs, Prentice-Hall.

Barry, J. and J. Proops. 1999. 'Seeking sustainability discourses with Q methodology', *Ecological Economics,* **28**: 337–45.

Bredahl, L. 1999. 'Consumers' cognitions with regard to genetically modified foods: Results of a qualitative study in four countries', *Appetite,* **33**(3): 343–60.

Brown, S.R. 1980. *Political Subjectivity: Application of Q Methodology in political science*. New Haven: Yale University Press.

Bruce, D. 2003. 'Contamination, crop trials, and compatibility', *Journal of Agricultural and Environmental Ethics,* **16**: 595–604.

Bruce, D.M. and J. Eldrige. 2000. 'The role of values in risk perception in the GM-debate', in M.P. Cottam, D.W. Harvey, R.P. Pape and J. Tait (eds), *Foresight and Precaution,* Volume 2 (Rotterdam: Balkema), pp. 855–62.

Busch, L., R. Grove-White, S. Jasanoff, D. Winickoff and B. Wynne. 2004. *Amicus Curiae Brief.* Submitted to the dispute settlement panel of the world trade organization in the case of EC: measures affecting the approval and marketing of biotech products. April 30.

Busch, L., W.B. Lacy, J. Burkhardt and L.R. Lacy. 1991. *Plants, Power, and Profit: Social, economic, and ethical consequences of the new biotechnologies*. Oxford: Basil Blackwell.

Caldart, C.C. 1983. 'Industry investment in university research', *Science, Technology and Human Values,* **8**(2): 24–32.

Carr, S. and L. Levidow. 1997. 'How biotechnology regulation separate ethics from risk', *Outlook on agriculture,* **26**(3): 145–50.

Conner, A.J., T.R. Glare and J.P. Nap. 2003. 'The release of genetically modified crops into the environment', *Plant Journal*, **33**(1): 19–46.

Cook, G., E. Pieri and P.T. Robbins. 2004. '"The scientists think and the public feels": expert perceptions of the discourse of GM food', *Discourse and Society*, **15**(4): 433–49.

Faber, M., R. Manstetten and J. Proops. 1996. *Ecological Economics: Concepts and methods*. Cheltenham: Edward Elgar.

Gaskell, G., N. Allum, M. Bauer, J. Durant, A. Allansdottir, H. Bonfadelli, D. Boy, S. de Cheveigne, B. Fjaestad, J.M. Gutteling, J. Hampel, E. Jelsoe, J.C. Jesuino, M. Kohring, N. Kronberger, C. Midden, T.H. Nielsen, A. Przestalski, T. Rusanen, G. Sakellaris, H. Torgersen, T. Twardowski and W. Wagner. 2000. 'Biotechnology and the European public', *Nature Biotechnology,* **18**: 935–8.

Gibbons, M. 1999. 'Science's new social contract with society', *Nature,* **402**: 6761 (Suppl).

Grove-White, R. 2001. 'New Wine, Old Bottles? Personal reflections on the New Biotechnology Commissions', *Political Quarterly,* October: 466–72.

James, C. 2002. 'Preview: Global status of commercialized transgenic crops: 2002', *ISAAA Briefs,* No 27. Ithaca, NY: ISAAA.

James, C. 2004. 'Preview: Global status of commercialized biotech/GM crops: 2004', *ISAAA Briefs*, No 32. Ithaca, NY: ISAAA.

Knight, F.V. 1921. *Risk, Uncertainty and Profit*. Boston: Houghton Mifflin Company.

Knight, J. 2003. 'A dying breed', *Nature,* **421**: 568–70.

Knorr-Cetina, K.D. 1981. *The Manufacture of Knowledge: An essay in the constructivists and contextual nature of science*. Oxford: Pergamon Press.

Krimsky, S. 1982. *Genetic Alchemy: The social history of the recombinant DNA controversy.* Cambridge, MA: MIT Press.

Krimsky, S. 1991. *Biotechnics and Society: The rise of industrial genetics*. New York: Praeger.

Krimsky, S. and R. Wrubel. 1996. *Agricultural Biotechnology and the Environment. Science, Policy, and Social Issues*. Illinois: University of Illinois Press.

Marris, C., B. Wynne, P. Simmons and S. Weldon. 2001. *Public Perceptions of Agricultural Biotechnologies in Europe*. Final Report of the PABE Research Project, December 2001.

McGloughlin, M. 1999. 'Ten reasons why biotechnology will be important to the developing world', *AgBioForum*, **2**(3&4): 163–74.

Meyer, G. and P. Sandøe. 2001. *Dialogue on Biotechnology in Relation to Plants*. Project Report 1. Frederiksberg: Centre for Bioethics and Risk Assessment.

Mulkay, M. 1979. *Science and the Sociology of Knowledge*. London: George Allen & Unwin.

National Research Council. 2000. *Gentically Modified Pest-Protected Plants*. Washington DC: National Academy Press.

Newberg, J.A. and R.L. Dunn. 2002. 'Keeping secrets in the campus lab: Law, values and rules of engagement for industry-university R&D partnerships', *American Business Law Journal,* **39**(2): 187–240.

Nielsen, T.H. 1997. 'Behind the color code of "no"', *Nature Biotechnology*, **XV**(13): 1320–21.

Nielsen, T.H. 2002. 'Traditional blue and modern green resistance', in M.W. Bauer and G. Gaskell (eds), *Biotechnology: The making of a global controversy* (Cambridge: Cambridge University Press), pp. 179–202.

Pickett, S.T.A., V.T. Parker and P.L. Fielder. 1992. 'The new paradigm in ecology: Implications for conservation biology above the species level', in P. L. Fiedler and S. K. Jain (eds), *Conservation Biology: The theory and practice of nature conservation, preservation and management* (London: Chapman and Hall), pp. 65–88.

Pistorius, R. and J. van Wijk. 1999. *The Exploitation of Plant Genetic Information: Political strategies in crop development*. Oxon: CABI Publishing.

Pretty, J. 2002. *Agri-Culture: Reconnecting people, land and nature*. London: Earthscan Publications.

Regal, P.J. 1994. 'Scientific principles for ecologically based risk assessment of transgenic organisms', *Molecular Ecology,* **3**: 5–13.

Restivo, S. 1995. 'The theory landscape in science studies: Sociological traditions', in S. Jasanoff, G.E. Markle, J.C. Petersen and T. Pinch (eds), *Handbook of Science and Technology Studies* (London: Sage publications), pp. 95–110.

Shackle, G.L.S. 1955. *Uncertainty in Economics and Other Reflections*. Cambridge: Cambridge University Press.

Sjöberg, L. 2002. 'The allegedly simple structure of experts' risk perception: An urban legend in risk research', *Science, Technology and Human Values,* **27**(4): 443–59.

Slovic, P. 2001. 'The risk game', *Journal of Hazardous Materials*, **89**: 17–24.

Spash, C.L. 2002. *Greenhouse Economics: Values and ethics*. London: Routledge.

Sterelny, K. and P.E. Griffiths. 1999. *Sex and Death: An introduction to philosophy of biology*. Chicago: The university of Chicago press.

Stirling, A. 1998. 'Risk at a turning point?', *Journal of Risk Research,* **1**(2): 97–109.

Stone, G.D. 2002. 'Both sides now: fallacies in the genetic-modification wars, implications for developing countries, and anthropological perspectives', *Current Anthropology,* **43** (4): 611–30.

Strand, R. 2001. 'The role of risk assessment in the governance of genetically modified organisms of agriculture', *Journal of Hazardous Materials*, **86** (1–3): 1997–204.

Strohman, R.C. 1997. 'The coming Kuhnian revolution in biology – Commentary', *Nature Biotechnology*, **15**(3): 194–199.

Tait, J. and L. Levidow. 1992. 'Proactive and reactive approaches to risk regulation – the case of biotechnology', *Futures,* **24**: 219–31.

Verhoog, H. 1993. 'Biotechnology and ethics', in T. Brante, S. Fuller and W. Lynch (eds), *Controversial Science: From content to contention* (New York: State University of New York Press), pp. 83–106.

Victor, D.G. and C.F. Runge. 2002. 'Farming the genetic frontier', *Foreign Affairs,* **81**(3): 107–14.

Wagner, W., N. Kronberger, N. Allum, S. Gheveignè, C. Diego, G. Gaskell, M. Heinssen, C. Midden, M. Ødegaard, S. Öhman, B. Rizzo, T. Rusanen and A. Stathopoulou. 2002. 'Pandora's genes – images of genes and nature', in M.W. Bauer and G. Gaskell (eds), *Biotechnology: The making of a global controversy* (Cambridge: Cambridge University Press), pp. 244–76.

Wilkins, J.L., V. Kraak, D. Pelletier, C. McCullum and U. Uusitalo. 2001. 'Moving from debate to dialogue about genetically engineered foods and crops: Insights from a Land Grant University', *Journal of Sustainable Agriculture*, **18**(2–3): 167–201.

Wilsdon, J., B. Wynne and J. Stilgoe. 2005. *The Public Value of Science: Or how to ensure that science really matters*. London: Demos.

Wolfenbarger, L.L. and P.R. Phifer. 2000.'The ecological risks and benefits of genetically engineered plants', *Science*, **290**: 2088–92.

Worster, D. 1990. 'The ecology of order and chaos', *Environmental History Review,* **14**: 1–18.

Wynne, B. 1992. 'Uncertainty and environmental learning: Reconceiving science and policy in the preventive paradigm', *Global Environmental Change,* **2**: 111–27.

Wynne, B. 2001. 'Creating public alienation: Expert cultures of risk and ethics on GMOs', *Science as Culture,* **10**(4): 445–81.

# Paper II

Ecological Economics 68 (2009) 2688–2695

Contents lists available at ScienceDirect

Ecological Economics

journal homepage: www.elsevier.com/locate/ecolecon

Analysis

# Institutions and the R&D of GM-crops

Valborg Kvakkestad

*Norwegian University of Life Sciences, Department of Economics and Resource Management, NO-1432 Aas, Norway*

ARTICLE INFO

*Article history:*
Received 8 October 2008
Received in revised form 3 April 2009
Accepted 6 May 2009
Available online 10 June 2009

*Keywords:*
GM-crops
Technology
Institutional shaping

ABSTRACT

This paper analyzes how different institutional structures shape the research and development (R&D) of genetically modified crops (GM-crops). Whether this R&D is conducted within companies, cooperatives or public research organizations (both publicly and privately funded R&D) is expected to influence the type of crops and traits that are developed and therefore the effects on society and ecosystems that potentially could follow from the use of GM-crops. This issue is analyzed empirically by statistical analysis of 1323 notifications for field trials with GM-crops that have been submitted under two EU Directives in seven European countries. The results show that the type of R&D organization influences the traits and crops that are developed. Companies are more likely to submit notifications that concern GM-crops that secure the potential for profit than are other types of R&D organizations, while R&D organizations that are purely publicly funded are more likely to submit notifications that only concern biosafety research than are cooperatives and companies. Consideration of the environment, food safety and food security might justify institutional reforms of R&D of GM-crops. This might include increased public funding combined with changes in intellectual property rights.



## 1. Introduction

This paper is about the influence of institutional structures on technological development. Technologies influence society by influencing how humans interact with each other and with nature. Genetically modified crops (GM-crops) have a huge potential to influence both society and ecosystems. Cultivating GM-crops might generally impose greater uncertainty compared to cultivating conventional crops, but the effects of GM-crops will vary from case to case depending on the type of crop that is modified and the variety of traits (the genetically modified characteristics) that are developed. GM-crops could both have positive and negative environmental and social effects depending on these relationships.

An important question is how society can reduce the potential for harm from GM-crops, and increase their potential for benefits. Technologies are shaped by the society and its institutional structures (Metcalfe, 1995). Institutions are sets of conventions, norms and laws that favor certain types of motivations and interests (Vatn, 2005). The hypothesis is that institutional structures for the R&D of GM-crops will influence the type of crops that are modified and the varieties of traits developed.

The focus of politicians considering GM-crop institutions has mainly been on developing intellectual property rights to facilitate privatization of research and then to regulate which GM-crops can be commercialized. However, if there are long time lags between the creation of the source of a negative effect and when that effect can be observed and standard burden of proof requirements are applied, regulation of such effects is difficult (Vatn, 2002). As well, regulations on which GM-crops can be commercialized will not secure the development of GM-crops that have positive effects on public goods like the environment.

A shift from state dominance of crop development to private dominance has occurred (Pistorius and van Wijk, 1999). The effect of this institutional change on which GM-crops are developed is given little attention in actual policymaking. There are, however, reasons to believe that the direction that the development of GM-crops takes is influenced by the different institutional contexts of universities and companies, as these contexts produce and protect different interests. Dasgupta and David (1994) emphasize that it is the nature of the goals, the norms of behavior, and the features of the reward systems that constitute the fundamental structural differences between university and company research. Company research is profit-motivated and characterized by short-term proprietary goals and secrecy (Lacy et al., in press). University research should ideally serve public needs and intellectual inquiry (Caldart, 1983) and is characterized by long-term research, self governance and control over the research agenda, open scientific communication and free use of the knowledge that is produced (Lacy et al., in press; Dasgupta and David, 1994). As plant biotechnology evolved, university research has, however, become more market oriented and private funding of university research has become more common (Shorett et al., 2003; Newberg and Dunn, 2002; Gibbons, 1999). Privately funded university researchers may be obligated to serve the interests of the shareholders, while there are no such obligations for purely publicly funded researchers. Agricultural cooperatives are also involved in development of GM-crops and it would be expected that their research would serve the interests of their farmer members.

*E-mail address:* valborg.kvakkestad@umb.no.

0921-8009/$ – see front matter © 2009 Elsevier B.V. All rights reserved.
doi:10.1016/j.ecolecon.2009.05.004

The aim of this paper is to study how the different institutional structures that are involved in different types of R&D organizations influence the kind of GM-crops developed. More specifically, we study a) what types of GM-crops are developed in companies, cooperatives and universities (both publicly and privately funded R&D), and b) what potential effects these types of institutional structures, through the products that are developed, will have on the environment, on food security and on food safety. These issues are addressed empirical by analyzing 1323 field trials with GM-crops that were submitted under the Deliberate Release Directives 90/220/EEC and 2001/18/EC in seven European countries.

## 2. A theoretical clarification of the institutional influence on the R&D of GM-crops

Different R&D organizations produce different incentives as a result of different institutional structures. This leads to different considerations being taken into account when developing GM-crops. Fig. 1 illustrates which parts of the feasibility set for GM-crops are expected to be realized under different R&D organizations.

Fig. 1 illustrates the parts of the technical feasibility set that are likely to be developed given the type of organization. The technical feasibility set is divided into different subsets (A–F) according to whether the specific subset creates profits, is legitimate to develop, and benefits members in farmer cooperatives.

The union of the feasibility sets of private, cooperative and public research is expected to be a subset of what is technically feasible. This is because some potential GM-crops are socially illegitimate. This is denoted by subset F in Fig. 1, which might contain GM-crops that yield profits, but in the long run will harm the reputation of the company.

Subsets C, D and E cover the parts of the feasibility set that can create the necessary economic returns in markets. This is a necessary condition for private R&D to take place. We would expect the crops resulting from this R&D to be excludable to allow the creation of necessary market revenues. The nature of plants implies, however, certain obstacles to excludability. First, crops are biological products that are easily reproduced. When seed transforms into a plant, the original seed is replaced by new seeds, which may be used as food products, or may be employed as a mean of production (as seed) for planting the next crop. Second, the costs related to crop-variety R&D are quite high. This combination of high R&D costs and low replication costs implies that the incentive for private investment in plant breeding is weak. Thus, to realize any of subsets C, D and E the seeds have to be excludable.

There are two ways of making seeds excludable: legally and biologically. Legal means to secure profits involve plant variety protection, patents, and contract growing. These means provide some, but not complete, protection for GM seeds (Srinivasan and Thirtle, 2003). First, the transaction costs of enforcing these intellectual property rights are high. Second, the existing intellectual property rights limit the possibilities for creating excludable seeds through legal means. Hence, it is in the interests of shareholders to develop biological means to secure a return on their investments.

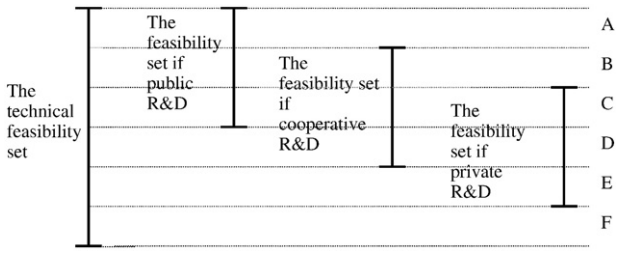


**Fig. 1.** Feasibility sets under different types of R&D organizations.

One of the most important biological mechanisms for securing a return on private investments—hybridization—has been available since the 1920s (Goeschl and Swanson, 2003; Ruttan and Hayami, 1984). Hybrid seeds are the product of the cross between two (or more) inbred lines. The seed of hybrid origin will lose some yield potential in subsequent generations, which drastically reduces farmers' incentives for seed saving. Despite of this property, hybrids have been widely used among farmers as hybrid varieties often have higher yields than open-pollinated varieties. This technology was, however, deliberately designed to obstruct the biological reproduction process (Pistorius and van Wijk, 1999). If the same effort had been put into developing open-pollinated varieties, they would probably be as good as hybrids (Kloppenburg, 2004). Subsets C, D, and E are expected to contain genetic modification of crops that already are biologically excludable by hybridization. Hybrid seed technology has been commercially successful for only some crops because it is expensive and often technically infeasible to produce hybrid seeds that have better agronomic characteristics than nonhybrid seeds. Biotechnology has, however, allowed the development of more economically feasible hybrid production systems.

A more recent example of a biological means to secure returns on private investments is Variety Genetic Use Restriction Technologies (V-GURTs), also called terminator technology (Eaton et al., 2002). This technology was first developed to prevent unwanted spread of transgenic traits by inserting a plant sterilization gene which makes the plant unable to produce fertile seeds (Purdue News, 2002). Seed companies were, however, interested in this technology because it ensures that seeds cannot be saved by farmers for subsequent planting.

Another biological means to make plant breeding more profitable is to develop traits by genetic engineering that complement traded inputs, i.e., the traits are only favorable if the farmer purchases the traded input. One example is the development of herbicide-tolerant GM-crops by companies that also market the particular herbicide to which the crop is tolerant. The potential of these GM-crops can be realized only when the herbicide is used.

Subsets C, D and E only include excludable GM-crops that are likely to yield profits. The capacity to create profits will increase if the crops and traits are widely demanded and if crops and traits can be developed at sufficiently low cost. The extent of traits that are difficult to develop might be limited since they are expensive to develop and have an uncertain probability of success.

The distinction between subsets C, D, and E in Fig. 1 is defined by how legitimate it is to develop the crop/trait in public research organizations. Universities may have a more narrow area to operate within than companies (illustrated by D and E), but also than cooperatives (illustrated by D). This does, however, depend on how market oriented university research is. In addition, there might be certain excludable GM-crops that yield profits, but are not favorable for farmers and therefore will not be developed by cooperatives (E). It could be argued that company R&D will not develop excludable GM-crops that are disadvantageous for farmers since the farmers would not buy these seeds. This assumes that farmers have a choice and that seed markets would be competitive (Srinivasan and Thirtle, 2003). However, the private seed industry has seen rapid consolidation through takeovers and mergers (Srinivasan and Thirtle, 2003).

Subset B contains GM-crops that are favorable for members in farmer cooperatives and legitimate to develop in public research organization, but that create too little profit to secure private investments. Whether this subset is actually realized by farmer cooperatives depends on the proportion of farmers who are members of the cooperative, the transaction costs of excluding others from the benefits of the cooperative plant breeding, and the capital yield claims.

Subset A illustrates the section of the feasibility set of GM-crops that are not expected to create sufficient profit to interest private capital and will not particularly benefit members in farmer cooperatives, but are considered legitimate to develop in public

research organizations. Thus, this part of the feasibility set can only be realized under public funding and might include crops that have positive effects on public goods such as the environment and food security. Crops that command only a small market and exhibit a high degree of geographical specificity might also be important (Pray and Umali-Deininger, 1998). Biosafety research on GM-crops that is not required by public authorities is another example of possible subset A research. Since scientists who work in public research organizations have to take less account of what is demanded by farmers and consumers, subset A might also contain crops that are considered problematic by farmers or consumers.

The feasibility set for R&D projects that have both public and private funding is likely to contain subsets B and C, but perhaps only a portion of subsets D and E since some projects might be unsuitable for public involvement, and perhaps also only a portion of subset A since not all projects will create the necessary returns on investments.

Other factors are also likely to influence the type of GM-crops that are developed. Countries might vary in their research cultures, the priorities of public authorities and the varieties of crops and traits that are important for the national agriculture. Time, i.e., the year the crops are developed, is also likely to influence which crops are developed. Country and year are therefore included as control variables in this study.

## 3. Methodology and data

To test whether the different organizations involved in R&D of GM-crops influence the varieties of GM-crops developed, we have tested the following hypotheses:

- **$H_1$:** The share of biologically excludable GM-crops is greater if the R&D is conducted by companies rather than cooperatives, and greater if by cooperatives than by public research organizations.

- **$H_2$:** The share of GM-crops that is likely to yield profits is greater if the R&D is conducted by companies than cooperatives, and greater if by cooperatives than by public research organizations.

- **$H_3$:** The share of biosafety research is greater in public research organizations than in cooperatives and greater in cooperatives than in companies.

For public research organizations we expect that R&D projects that have both public and private involvement would be more similar to R&D projects conducted by companies and cooperatives than R&D projects that only have public involvement.

These hypotheses are tested with data from field trials with GM-crops in the EU. Field trials are a prerequisite step when applying for market approval. The old and the new Deliberate Release Directives in the EU require that before undertaking a field trial, a notification shall be submitted. The database that we have used is based on a summary of each notification and is termed the SNIF (summary notification information format) database.[1] Our analysis is based on data from the period when the database was set up (October 1991) until June 2005. We limited our sample to seven countries: Denmark, Finland, France, Germany, Sweden, Spain, and the United Kingdom. Notifications from these countries represent about 70% of all notifications submitted in this period.

The database provides information on the name of the plant, the main trait, the name of the notifiers (organizations that have submitted field trial notifications), the year the notification was submitted and the country where the field trial should take place. For notifications submitted under the new directive, the summary of the notifications is also available.

From the information provided on the websites of the notifiers, the different types of R&D organizations were categorized into companies, cooperative mix,[2] public research organization, other organizations (organizations that do not fit in any of the other groups), and unknown organizations (organizations for which we were unable to find any information). Questionnaires were sent to 264 public research organizations, 'other' research organizations and one company whose website stated that they received public funding, to check if the specific project had received private funding. The response rate was 72%. Companies or 'cooperative mix' received no questionnaires because the extent of public funding in these organizations was expected to be limited.

Since we have different combinations of type of organization and funding (private or public) we term these different combinations 'interests'. 'Interests' refers to the interests that are produced by the institutional structures that exist in different types of organizations with different types of funding. Based on the answers to the questionnaires, notifications submitted by public research organizations and other organizations were categorized into public mix,[3] pure public,[4] public unknown,[5] and other organizations with unknown funding.

Five logistic regression models were analyzed. Models A and B are related to Hypothesis 1, Models C and D are related to Hypothesis 2, and Model E to Hypothesis 3. Table 1 presents Models A–E.

Models A, B, C and D include the same independent variables. In the EU a *de facto* moratorium on the release of genetically modified organisms as commercial products was established in 1999. This moratorium was lifted in 2004 when the European Commission approved a GM maize for import. No authorizations for cultivation have, however, been granted since 1998. Years are categorized into two time periods, the period before the moratorium (1991–1998) and the period during and after the moratorium (1999–2005).

The dependent variable in Model A equals 1 if the notifications relate to crops that have become biologically excludable by genetic modification. This includes V-GURTs, crops that are genetically modified to produce hybrid seeds (termed 'restoration of male sterility/fertility' in the database), or traits developed by biotechnology that complement traded inputs. The last mentioned type of notifications concerns herbicide-tolerant GM-crops that are produced by companies that also produce the particular herbicide to which the crop is tolerant. This mainly concerns notifications that include tolerance to glufosinate and are submitted by AgrEvo, Aventis Crop Science, Bayer Crop Science or Plant Genetic Systems, or notifications submitted by Monsanto that include tolerance to glyphosate or notifications submitted by Rhône-Poulenc Agro that include tolerance to isoxazole or oxynil.

In Model B the dependent variable equals 1 if the notifications relate to crops that have become biologically excludable by genetic modification and/or crops where hybrids are widely used (biologically excludable by hybridization). Crops where hybrids are widely used include broccoli, cabbage, cauliflower, chicory, fodder beet, maize, melon, radish, squash, sugar beet, sunflower and tomato (accomplished by advices from experts in plant breeding). Recently hybrids have become quite common for oilseed rape. This crop is,

[1] This database is available on http://gmoinfo.jrc.it/.

[2] Notifiers that either are cooperatives or corporations owned—partly or fully—by cooperatives, or in the case that the notifications involve more than one notifier, notifications that are submitted by a company and a cooperative or corporations owned by a cooperative. Cooperatives are included in this category because the database contains only a few pure cooperatives.

[3] (a) The R&D of GM-crop(s) is partly/fully privately funded and the notification is submitted by a public research organization, or b) the notification is submitted by a public research organization and a company or a 'cooperative mix', or an 'other' organization, or c) the R&D of GM-crop(s) is fully or partly publicly funded and the notification is submitted by an 'other' organization or a company.

[4] The R&D of GM-crop(s) is fully publicly funded and conducted by a public research organization.

[5] The notification is submitted by a public research organization, but the funding of the R&D is unknown.

**Table 1**
Variables included in the logistic regression models.

| Independent variables | Model | | | | |
|---|---|---|---|---|---|
| | A | B | C | D | E |
| | $Y=1$ if (0 otherwise) | | | | |
| | Biologically excludable by biotechnology | Biologically excludable by biotechnology or hybrid | Area of production of the crops > 50,000 ha | Traits are difficult to develop | Biosafety research |
| Interests[a] | X | X | X | X | X |
| Company | | | | | |
| Cooperative mix | | | | | |
| Public mix | | | | | |
| Pure public | | | | | |
| Country[a] | X | X | X | X | |
| Denmark | | | | | |
| Finland | | | | | |
| France | | | | | |
| Germany | | | | | |
| Spain | | | | | |
| Sweden | | | | | |
| UK | | | | | |
| Year[a] | X | X | X | X | |
| 91–98 | | | | | |
| 99–05 | | | | | |
| Year[b] | | | | | X |
| Attitude moratorium[a] | | | | | X |
| Support | | | | | |
| No support | | | | | |

[a]Dummy variables.
[b]Continuous variable (2002–2005).
'X' denotes that the variable is included in the model.

however, not categorized as a crop where hybrids are widely used since hybrids have been rare for this crop for most of the period studied in this paper. Although hybrids are widely used for a particular crop, this does not necessary mean that the crop included in the notification is a hybrid. This is, however, not expected to be a major source of error.

To test Hypothesis 2 it would be preferable to employ data for sale of seeds, as that would be the most adequate measure for demand for seeds. These data were, however, not available. Instead, data on the area sown to these crops were used (Eurostat, 2008a,b). An annual average area for each crop in the time period 1991–2005 was calculated. The dependent variable in Model C equals 1 if the crop(s) in the notification was(were) grown on more than 50,000 ha in the country where the notification was submitted. Trees were excluded from the analysis since there are different laws on the use of forest land and agricultural land. Tall fescue—a grass forage—was also excluded since the area of production of this crop was unclear. Notifications that contained more than one crop were excluded from the analysis if the notification contained one crop that was grown on more than 50,000 ha and one crop that was grown on less than 50,000 ha.

For Model C it can be questioned whether it is only the national market that is relevant. The potential market for a Swedish field trial crop might also for example include the Danish market. Calculating the relevant market for each field trial crop would, however, be quite complicated and require information that is unavailable for the author. Also, another split point than 50,000 ha could have been chosen. In most of the countries, this number appeared to produce a reasonable grouping. In three of the countries there were no crops that were grown on an area between 40,000 and 50,000 ha, and only one country had crops that were grown on an area greater than 45,000 ha but less than 50,000 ha.

The dependent variable in Model D equals 1 if the notifications contain traits that are difficult to develop like fungi resistance, resistance to abiotic stress and alteration of amino acid metabolism. This categorization was done with the help of an expert in plant biotechnology, who was unable to categorize 29 notifications. These notifications are therefore excluded from the sample when analyzing Model D. This type of categorization involves of course an element of judgment.

Model E concerns whether the notification involves biosafety research. This is determined by analyzing the summary of the notifications[6] that are submitted under the new Deliberate Release Directive. The notifications that are submitted under the old Deliberate Release Directive are excluded since there was no information available on biosafety research for these notifications. Based on the summaries of the notifications, the notifications are categorized into three groups: a) summaries where it is stated that the notifications only include biosafety research (pure biosafety research), b) summaries where it is stated that the notification includes biosafety research and other purposes, and c) notifications where no biosafety research is mentioned. Examples of groups a) and b) are summaries where it is stated that "The purpose of this release is to … address biosafety implications of pollen movement and evaluating the impact (if any) of transgenes on farming activity and on the environment" or that the purpose of the project are "Study on the ecological impact and the efficacy against the bacterial pathogens *Ralstonia solanacearum*.". Where the notifications include pure biosafety research it is likely that this biosafety research is unrequired by the authorities. Where the notifications concern biosafety research and another purpose it is difficult to decide whether the biosafety research is required by the authorities or not since some biosafety research is required for all field trials. It might be that the only difference between notifications b) and c) is whether required biosafety research is mentioned or not. The number of summaries where it is stated that the notifications include pure biosafety research is zero for many of the categories. Hence, it was impossible to estimate a logistic regression model for pure biosafety research. The dependent variable in Model E therefore equals 1 if it is stated in the summary that the notification concerns pure biosafety research (a) or biosafety research combined with other purposes (b).

The independent variable 'interests' is the same for Model E as for the other models. Since only notifications that are submitted under the new Deliberate Release Directive are included, time of notification is measured as a continuous variable (2002–2005). Countries are categorized into countries that supported the moratorium and those that did not (UK and Spain). It might be expected that countries that supported the moratorium are more likely to conduct biosafety research since they are more concerned about the involved risks.

All five models are analyzed by binary logistic regression. Except for the variable 'year' in Model E, the independent variables are dummy variables. Odds ratios (ORs) for each variable are presented. OR is a way of comparing whether the probability of a certain event is the same for two groups. An OR of 1 implies that the event is equally likely in both groups. An OR greater than 1 implies that the event is more likely in the first group. An OR less than 1 implies that the event is less likely in the first group. While all the different interests are compared against each other, each country is only compared against a reference country (UK).

Since it was impossible to analyze the extent of pure biosafety research by logistic regression, the association between pure biosafety research and the independent variables in Model E is analyzed by Fisher's exact test. This test was applied instead of the chi-square test since the cells have expected counts of less than five. If the overall test for a variable was found to be significant ($p<0.05$), multiple

[6] The summaries are available on http://gmoinfo.jrc.ec.europa.eu/gmp_browse.aspx.

**Table 2**
Percentage distribution of notifications submitted by the interests involved by time period and country.

| | Company | Cooperative mix | Public mix | Pure public | Public research org. and unknown funding | Other | Unknown org. | Total *N* |
|---|---|---|---|---|---|---|---|---|
| Year | | | | | | | | |
| 91–93 | 61 | 10 | 8 | 5 | 7 | 0 | 8 | 83 |
| 94–96 | 54 | 20 | 8 | 8 | 2 | 3 | 5 | 409 |
| 97–99 | 56 | 23 | 3 | 10 | 2 | 2 | 2 | 496 |
| 00–02 | 55 | 15 | 2 | 16 | 8 | 3 | 1 | 174 |
| 03–05 | 58 | 12 | 15 | 11 | 4 | 1 | 0 | 161 |
| Country | | | | | | | | |
| Denmark | 83 | 10 | 5 | 0 | 3 | 0 | 0 | 40 |
| Finland | 30 | 0 | 15 | 35 | 5 | 15 | 0 | 20 |
| France | 49 | 30 | 5 | 9 | 0.4 | 4 | 3 | 546 |
| Germany | 48 | 3 | 3 | 36 | 8 | 0 | 1 | 147 |
| Spain | 67 | 9 | 7 | 3 | 6 | 0.4 | 8 | 274 |
| Sweden | 38 | 39 | 11 | 6 | 3 | 4 | 0 | 80 |
| UK | 67 | 10 | 8 | 6 | 5 | 3 | 1 | 216 |
| All | 56 | 19 | 6 | 10 | 3 | 2 | 3 | |
| Total *N* | 738 | 249 | 82 | 135 | 45 | 33 | 41 | 1323 |

comparison methods were employed to assess the pairwise comparisons. A *t*-test for the mean was used to look for differences between interests, states and years.

## 4. Results

In this section we present the share of notifications submitted by different interests for each country and for each year (Table 2) and the share of different traits and crops by interest (Table 3). We then analyze Models A, B, C, D and E (Tables 4–7).

Of the total number of notifications submitted, most (68%) were submitted between 1994 and 1999, and most of these were submitted by France (41%) and Spain (21%). In our sample, 'company' is the main interest involved in field trials on GM-crops followed by 'cooperative mix', 'pure public' and 'public mix'. Denmark, Spain and the UK have the highest company involvement, Sweden and France have the highest 'cooperative mix' involvement and Finland and Germany have the highest public involvement. We then excluded 'public research organization and unknown funding', 'other' and 'unknown organization' from our analysis. In Table 3 traits are categorized[7] into input traits, male sterility, output traits, markers, and other traits. Input traits influence the performance of the plant during germination and growth in the field, while output traits bring benefits to consumers and food processors.

Table 3 shows that four crops (maize, oilseed rape, potato, and sugar beet) and two traits (herbicide tolerance and insect resistance) are included in more than 80% of all field trial notifications. The main similarities are that oilseed rape is important for all interests, while cotton, fodder beet, tomato, wheat, and other oil seeds are of little importance for all. Except for these similarities, we observe great differences between the interests. Examples are that maize and herbicide tolerance are very important for 'company' and 'cooperative mix', but less important for 'pure public'. Rice and tobacco are only important for 'public mix', while trees and other traits are only important for 'pure public'. Another difference is that 'pure public' has greater variation in the type of crops that are included in their notifications compared to the other interests.

[7] The categorization was done with the help of Annex B in Lheureux et al. (2003) and with the help of experts on plant biotechnology.

**Table 3**
Percentage distribution of crops and traits by involved interest[a].

| | Company | Cooperative mix | Public mix | Pure public | All | Total *N* |
|---|---|---|---|---|---|---|
| Crops | | | | | | |
| Cotton | 3 | 0 | 0 | 1 | 2 | 21 |
| Fodder beet | 3 | 2 | 1 | 1 | 3 | 32 |
| Fruit and berries[b] | 0 | 0 | 4 | 4 | 1 | 8 |
| Maize | 35 | 46 | 11 | 3 | 32 | 387 |
| Oilseed rape | 24 | 19 | 27 | 21 | 23 | 273 |
| Potato | 9 | 11 | 6 | 29 | 12 | 140 |
| Rice | 0 | 0 | 22 | 4 | 2 | 24 |
| Sugar beet | 19 | 9 | 5 | 4 | 14 | 168 |
| Tobacco | 2 | 6 | 18 | 5 | 4 | 52 |
| Tomato | 2 | 1 | 0 | 0 | 1 | 18 |
| Wheat | 1 | 2 | 2 | 1 | 1 | 16 |
| Trees[c] | 1 | 0 | 1 | 12 | 2 | 21 |
| Other oilseeds[d] | 3 | 3 | 0 | 1 | 2 | 29 |
| Other vegetables[e] | 2 | 2 | 1 | 10 | 3 | 37 |
| Other crops[f] | 1 | 0.4 | 2 | 8 | 1 | 18 |
| Traits | | | | | | |
| Input traits | | | | | | |
| Herbicide tolerance | 73 | 59 | 37 | 29 | 63 | 756 |
| Insect resistance | 22 | 13 | 10 | 8 | 18 | 218 |
| Resistance to pathogens[g] | 9 | 8 | 10 | 20 | 10 | 125 |
| Abiotic stress/yield | 1 | 9 | 34 | 15 | 6 | 76 |
| Male sterility | 12 | 5 | 12 | 2 | 9 | 113 |
| Output traits[h] | 12 | 32 | 41 | 34 | 20 | 246 |
| Marker | 2 | 1 | 5 | 8 | 2 | 30 |
| Other traits[i] | 0.4 | 0 | 1 | 8 | 1 | 15 |

[a] Some notifications include more than one crop and/or one trait so the total number of crops and traits is higher than the number of notifications and the percentages sum to more than 100.
[b] The fruit and berries are apple, grape, pear, and strawberry.
[c] Trees include aspen, birch, eucalyptus, pine, poplar, and spruce.
[d] Other oilseeds include soybean, sunflower, and turnip rape.
[e] Other vegetables include beet, broccoli, cabbage, cauliflower, chicory, lettuce, melon, pea, radish, sea beet, spinach, and squash.
[f] Other crops include alfalfa, barley, black nightshade, flax, petunia, robusta, rose gum, tall fescue, and thale cress.
[g] These pathogens include fungi, bacteria, virus, and other species.
[h] Output traits include modified nutrients/ingredients, industrial use, health, modifications of color/form, and modification of ripening.
[i] Other traits include downregulation of systemin, trypsine proteinase inhibitor, and the floral homeotic gene to induce sterility, as well as gene silencing, monitoring transgene flow, phytoremediation of soils, study of promoter regulation, and testing of gene expression and gene stability.

### 4.1. Biologically excludable crops

The shares of notifications that contain crops that have become biologically excludable by biotechnology (Model A) are 41, 16, 13, and 3% respectively for 'company', 'cooperative mix', 'public mix' and 'pure

**Table 4**
OR estimates for Models A and B by binary logistic regression.

| | Model A $N=1204$ | | Model B $N=1204$ | |
|---|---|---|---|---|
| | OR | 95% CI | OR | 95% CI |
| Company vs. cooperative mix | 4.2** | 2.8–6.1 | 3.3** | 2.2–4.8 |
| Company vs. public mix | 4.7** | 2.4–9.2 | 12.8** | 7.3–22.2 |
| Company vs. pure public | 25.1** | 9.1–69.4 | 38.9** | 21.3–71.0 |
| Cooperative mix vs. public mix | 1.1 | 0.5–2.4 | 3.9** | 2.2–7.0 |
| Cooperative mix vs. pure public | 6.0** | 2.1–17.6 | 11.9** | 6.3–22.2 |
| Public mix vs. pure public | 5.3** | 1.6–17.5 | 3.0** | 1.4–6.4 |
| '99–05' vs. '91–98' | 0.8 | 0.6–1.1 | 1.1 | 0.8–1.5 |
| Denmark vs. UK | 0.2** | 0.1–0.5 | 2.0 | 0.9–4.6 |
| Finland vs. UK | 0.3 | 0.1–1.5 | 3.0 | 0.7–11.7 |
| France vs. UK | 0.7* | 0.5–0.9 | 5.5** | 3.6–8.4 |
| Germany vs. UK | 0.6 | 0.4–1.0 | 0.9 | 0.5–1.6 |
| Spain vs. UK | 0.4** | 0.2–0.6 | 3.1** | 1.9–5.0 |
| Sweden vs. UK | 0.4* | 0.2–0.8 | 0.5* | 0.3–0.9 |

*$p<0.05$, **$p<0.01$.

**Table 5**
OR estimates for Models C and D by binary logistic regression.

| | Model C $N=1175$ | | Model D $N=1147$ | |
|---|---|---|---|---|
| | OR | 95% CI | OR | 95% CI |
| Company vs. cooperative mix | 1.7* | 1.1–2.7 | 0.3** | 0.2–0.5 |
| Company vs. public mix | 3.9** | 2.1–7.3 | 0.1** | 0.1–0.2 |
| Company vs. pure public | 6.6** | 3.6–11.9 | 0.2** | 0.1–0.3 |
| Cooperative mix vs. public mix | 2.3 | 1.2–4.5 | 0.4** | 0.2–0.7 |
| Cooperative mix vs. pure public | 3.9** | 2.1–7.4 | 0.6 | 0.4–1.0 |
| Public mix vs. pure public | 1.7 | 0.8–3.6 | 1.5 | 0.8–2.7 |
| '99–05' vs. '91–98' | 2.3** | 1.5–3.5 | 1.3 | 1.0–1.9 |
| Denmark vs. UK | 0.1** | 0.0–0.2 | 0.5 | 0.2–1.4 |
| Finland vs. UK | 0.0** | 0.0–0.1 | 0.5 | 0.2–1.7 |
| France vs. UK | 0.6 | 0.3–1.0 | 0.4** | 0.2–0.6 |
| Germany vs. UK | 2.3 | 0.8–6.3 | 0.6 | 0.3–1.1 |
| Spain vs. UK | 0.6 | 0.3–1.2 | 0.4** | 0.2–0.6 |
| Sweden vs. UK | 0.1** | 0.0–0.1 | 0.3** | 0.1–0.6 |

*$p<0.05$, **$p<0.01$.

public'. None of these crops is V-GURTs. All the traits that complemented traded inputs concerned herbicide-tolerant crops that were submitted by organizations that also market the particular herbicide. The shares of notifications that contain crops that are biologically excludable by biotechnology and/or hybrid (Model B) are respectively 80, 64, 29, and 11% for 'company', 'cooperative mix', 'public mix', and 'pure public'. Table 4 presents the OR estimates for Models A and B.

The OR in Table 4 shows that for both models all four interests differ significantly from each other, and that they differ in the following order concerning the probability that the crop is biologically excludable: 'company', 'cooperative mix', 'public mix', and 'pure public'. The exception is that 'cooperative mix' does not differ significantly from 'public mix' for Model A. 'Company' is, for example, 25 times more likely to submit notifications that contain crops that have become biologically excludable by biotechnology than is 'pure public'. The UK (for Model A) and France (for Model B) are most likely to develop excludable crops, while Denmark (for Model A) and Sweden (for Model B) are least likely to submit these types of crops.

### 4.2. GM-crops that are likely to yield profits

The shares of notifications that contain crops that are grown on more than 50,000 ha (in the country where the notification is submitted) are respectively 91, 82, 71, and 75% for 'company', 'cooperative mix', 'public mix', and 'pure public'. The corresponding numbers for the shares of notifications that contain traits that are difficult to develop are 12, 24, 47, and 40%. Table 5 presents the OR for Models C and D.

From Table 5 we observe that 'company' is more likely to submit notifications that concern crops that are widely grown (Model C) and traits that are easy to modify (Model D) than all the other interests. For Model C, 'cooperative mix' is more likely to submit these types of notifications than is 'pure public' and for Model D, 'cooperative mix' is more likely to submit these types of notifications than is 'public mix'. Notifications submitted under and after the moratorium are more likely to contain crops that are relatively widely grown than those submitted before the moratorium. For Model D there is no significant difference between the time periods, although one might expect the share of difficult traits to increase with time as more knowledge is gained on how to develop traits.

**Table 6**
The extent of pure biosafety research by interests, attitude to moratorium and year.

| Independent variables | Pure biosafety research[1] | | Total no. of notifications |
|---|---|---|---|
| | *N* | % | |
| Interests* | | | |
| Company | 0 | 0[a] | 97 |
| Cooperative mix | 0 | 0[a] | 18 |
| Public mix | 1 | 4[ab] | 24 |
| Pure public | 4 | 19[b] | 21 |
| Attitude moratorium | | | |
| Support | 4 | 5 | 82 |
| No support | 1 | 1 | 78 |
| Year | | | |
| 2002 | 0 | 0 | 8 |
| 2003 | 3 | 5 | 66 |
| 2004 | 1 | 2 | 47 |
| 2005 | 1 | 3 | 39 |
| All | 5 | 3 | 160 |

[1]The relationship between pure biosafety research and the overall effect of the independent variables is analyzed by Fisher's exact test. *$p<0.01$.
[a–b]Since Fisher's exact test suggests that the overall effect of 'interests' is significant, the differences between different interests are analyzed. Different superscripts imply significant differences ($p<0.05$). If, for example, two cells both have the superscript a, they do not differ, while if one of the cells has the superscript a while the other cell does not have this superscript, they differ.

### 4.3. Notifications that include biosafety research

Since it was impossible to analyze the extent of pure biosafety research by logistic regression, the number of notifications with pure biosafety research as well as the results of Fisher's exact tests and the multiple comparison tests is presented in Table 6. The total number of notifications remaining in our analysis is 160 because we include only notifications submitted under the new Deliberate Release Directive.

Table 6 shows that the extent of pure biosafety research is very limited. Only 3% of the notifications submitted under the new Deliberate Release Directive concern pure biosafety research. All but one of these notifications were submitted by 'pure public', one was submitted by 'public mix' and none by the other interests. The extent of pure biosafety research is significantly lower for 'company' and 'cooperative mix' than for 'pure public'. Table 7 presents the OR estimates for Model E—the model that includes both 'pure biosafety research' and 'biosafety research combined with other purposes'. The shares of notifications that contain this type of research are respectively 7, 17, 79, and 33% for 'company', 'cooperative mix', 'public mix', and 'pure public'.

Table 7 reveals that 'company' is less likely than all the other interests to submit notifications where it is stated that biosafety research is the only purpose of the field trial or that biosafety research is part of the field trial. There are no significant differences between the other interests. Surprisingly, states that supported the moratorium are less likely to submit notifications that include some kind of biosafety research than are states that did not support the moratorium.

**Table 7**
OR estimates for Model E by binary logistic regression.

| | Model E $N=160$ | |
|---|---|---|
| | OR | 95% CI |
| Company vs. cooperative mix | 0.1* | 0.0–0.8 |
| Company vs. public mix | 0.0** | 0.0–0.1 |
| Company vs. pure public | 0.1** | 0.0–0.3 |
| Cooperative mix vs. public mix | 0.2 | 0.0–1.1 |
| Cooperative mix vs. pure public | 0.5 | 0.1–2.4 |
| Public mix vs. pure public | 3.1 | 0.6–14.8 |
| States not supporting the moratorium vs. states supporting the moratorium | 4.4* | 1.2–16.3 |
| Year (2002–2005) | 0.9 | 0.5–1.6 |

*$p<0.05$, **$p<0.01$.

## 5. Discussion

### 5.1. Institutional context and R&D of GM-crops

The results show that 'companies' are the main interest involved in R&D of GM-crops. Although it is being emphasized that university

biotechnology research has become more market oriented and that private funding of university research has become more common, our results show that more than half of the notifications submitted by public R&D organizations are fully publicly funded and that 'public mix' and 'pure public' differ significantly from 'company' in all five models. 'Public mix' differs significantly from 'pure public' in two of the five models. Hence, the results show that private involvement in public research influences R&D, but that this type of research nevertheless differs from pure private research.

We observe that the institutional context influences the type of crops and traits that are developed. Generally the analyses of the models support our hypotheses. The analyses show that all four interests differ significantly from each other and that they differ in the following order concerning the probability that the crop is biologically excludable (Models A and B), the probability that the crop is widely grown (Model C) and the probability that the traits are easy to develop (Model D); 'company', 'cooperative mix', 'public mix', and 'pure public'. Exceptions are that 'cooperative mix' does not differ significantly from 'public mix' for Models A and C, that 'public mix' does not differ significantly from 'pure public' in Models C and D, and that 'cooperative mix' does not differ significantly from 'pure public' in Model D. For Model E (field trials that concern some kind of biosafety research) there are no significant differences between the interests except that 'company' differs from all the other interests. The extent of pure biosafety research is significantly lower for 'company' and 'cooperative mix' than for 'pure public'. Hence, except in the last case, 'company' is the interest that always differs from the other interests, while the other interests sometimes differ significantly from each other and sometimes not. Although we observe that the share of different types of notifications varies between the interests, it is also the case that almost all the traits and crops that are developed by 'company', 'cooperative mix', and 'public mix' are also developed by 'pure public'. All the traits and crops that are developed by 'pure public' (including pure biosafety research) are, however, not developed by the other interests. Hence, the different interests result in different focus in their R&D of GM-crops and if 'pure public' disappeared, some traits, crops and types of research would not be developed.

Although some countries differ significantly from UK in all models, there is no clear pattern of which countries that differ and in what order. Concerning time, there was no difference between the period before or after the moratorium was established, except that notifications submitted under and after the moratorium are more likely to contain crops that are widely grown than those submitted before the moratorium. It is perhaps surprising that the moratorium does not have any effect, as that event represented a radical shift in the possibility to market GM-crops.

Welsh and Glenna (2006) have undertaken a similar study of a database on GM-crop field trial applications in the US from 1993 through 2002. Parallel to my findings in Tables 3 and 5 they found that companies were more likely to focus on major crops and major traits like herbicide tolerance and insect resistance than universities and foundations. The authors did, however, observe that over time the universities more closely paralleled private sector research trends, indicating that university research has become more market oriented.

### 5.2. Environment, food safety, and food security

One important question is what potential effects on the environment, food safety, and food security might follow if the GM-crops in the notifications are cultivated or used as food or feed. Many of the effects from GM-crops are uncertain and disputed. The effects from the involvement of different interests in the R&D of GM-crops are therefore also uncertain and disputed.

The interests differ on the extent of biologically excludable crops. In our study biologically excludable crops refer to crops that are genetically modified to produce hybrid seeds, crops where hybrids are widely used, and herbicide-tolerant crops that were submitted by organizations that also market the particular herbicide. Although hybrids are likely to increase yields, they could affect food security negatively since farmers are dependent on buying new seeds if the quality and level of the yield are to be maintained. Herbicide-tolerant crops have the potential to create a weed-management problem by increasing the extent of herbicide-resistant weeds (GM Science Review Report, 2003). One of the important concerns with the effects of herbicide-tolerant weeds is, therefore, that it might cause more damaging pest-control systems.

Most of the interests also differ in the likelihood of submitting notifications of crops that are grown on areas with little commercial interest. Involving public R&D will not necessary imply risk reduction since it may actually increase the area cultivated with GM-crops. However, if the results are transferred to plant breeding generally, the development of crops that are grown on areas with little commercial interest might increase food security since farmers who command only a small market will also get access to improved plant material. Whether the environmental risks increase if the area that potentially could be cultivated with GM-crops increases also depends on whether the risks from GM-crops that are developed by 'pure public' are similar to the risks from GM-crops developed by, for example, 'company'.

The interests also differ in the extent of biosafety research. Biosafety research, and especially pure biosafety research, is essential to avoid negative effects on the environment, food security and food safety.

### 5.3. Future choice of institutional structures

An important question is whether there is any need for institutional change concerning the R&D of GM-crops. There are several indications for an increase in the role of public R&D. One of the main reasons that the public has been critical of GM-crops is the dominance of private interests (Marris et al., 2001). The (positive and negative) effects that GM-crops potentially could impose on the environment, food security, and food safety justify increased public R&D since these issues represent, in general, benefits and costs external to the private sector. The protection of the farmers' right to save seeds may also justify public involvement. The importance of agriculture for rural settlement and cultural heritage might also justify public plant breeding so that marginal agricultural areas get access to improved plant material.

Private involvement in plant breeding increased substantially because biotechnology allowed greater control over the genetic characteristics of plants and facilitated the protection of biotechnological innovations under patent law (Van Wijk, 2004). In fact, current patent laws strongly favor large companies and the development of new varieties now requires access to a number of biotechnological processes patented by different companies. The ability to license processes often depends on the R&D organization having a portfolio of patents for cross-licensing (Srinivasan and Thirtle, 2003). Hence, the more patents you have, the better. This is one of the main reasons for the many mergers and acquisitions among agricultural biotechnology companies. Public research organizations often have few patents and cannot afford to pay license fees, drastically reducing their ability to be involved in applied plant biotechnology. Financial support for public sector agricultural research has also suffered a serious setback (Srinivasan and Thirtle, 2003). To increase public involvement in the R&D of GM-crops, intellectual property rights might need to be reduced and public funding increased. Only reducing intellectual property rights is insufficient because that might increase the emphasis on biologically excludable crops such as V-GURTS within the private sector, and public researchers would, of course, need

increased funding for this research. The findings of Welsh and Glenna (2006) do, however, imply that only increasing public involvement, might be insufficient. Institutional reforms that can reverse the commercialization of university research might also be needed.

## 6. Conclusion

This paper illustrates the importance of the different institutional structures for the varieties of GM-crops developed, and thereby the effects that potentially could follow from the use of GM-crops. We expected that the likelihood of developing biologically excludable crops, crops that are widely grown, traits that are easy to develop and notifications that do not concern any or pure biosafety research would be greater if the R&D was conducted by companies than by cooperatives, and greater in cooperatives than in public research organizations. We also expected that R&D having both public and private involvement ('public mix') would be more similar to R&D conducted by cooperatives and companies than R&D that only had public involvement ('pure public'). Since only a few notifications were submitted by pure cooperatives, the category 'cooperative' was redefined to 'cooperative mix', meaning notifiers with some kind of cooperative involvement. Our expectations were generally confirmed by the results. For the issues studied company differed significantly from all the other interests in the following order; 'cooperative mix', 'public mix', and 'pure public'. One exception was that for traits that are easy to develop, company differed more from 'public mix' than from 'pure public'. 'Cooperative mix' differed from 'pure public' on most of the issues, while 'cooperative mix' and 'public mix' as well as 'public mix' and 'pure public' were more similar.

'Company' and 'cooperative mix' were likely to submit notifications involving biologically excludable crops. These interests are therefore likely to develop GM-crops that might increase agricultural weed-management problems and crops that can affect food security negatively if the supply of seeds to farmers is hampered. Since 'company' is less likely than all other interests to conduct any kind of biosafety research and because the extent of pure biosafety research is significantly lower for 'company' and 'cooperative mix' than for 'pure public', 'pure public' research is more likely to result in knowledge about negative effects on the environment, food security and food safety than 'company' and 'cooperative mix'. Because 'pure public' is more likely than 'company' and 'cooperative mix' to submit notifications for crops that are not widely grown, the area that potentially could be sown to GM-crops could increase as a result of pure public funding because farmers that command only a small market could also get access to GM seeds.

The empirical results of this study, public distrust in private research, and the importance of GM-crops for public goods such as the environment, food security and food safety justifies institutional reforms to increase public R&D of GM-crops. These reforms might include increased public funding combined with changes in intellectual property rights. Overproduction of food in western countries during the 1980s and 1990s has been replaced by global food shortages. This might increase awareness of the importance of public plant breeding.

## Acknowledgments

I am grateful to Arild Vatn and two anonymous referees for their constructive and helpful feedback on this manuscript. Advice from Knut Gunnar Berdal, Åsmund Bjørnstad, Merethe Aasmo Finne, Ola Flaten, Arne Gillund, Eline Benestad Hågvar, Odd Arne Rognli and Bell Batta Torheim are also gratefully acknowledged.

## References

Caldart, C.C., 1983. Industry investment in university research. Science, Technology & Human Values 8 (2), 24–32.
Dasgupta, P., David, P.A., 1994. Towards a new economics of science. Research Policy 23, 487–521.
Eaton, D., Van Tongeren, F., Louwaars, N., Visser, B., Van der Meer, I., 2002. Economic and policy aspects of 'terminator' technology. Biotechnology and Development Monitor 49, 19–22.
Eurostat, 2008a. Table APRO_CPP_CROP = Crops products (excluding fruits and vegetables) (annual data). Available at http://epp.eurostat.ec.europa.eu/extraction/evalight/EVAlight.jsp?A=1&language=en&root=/theme5/apro/apro_cpp_crop.
Eurostat, 2008b. Table APRO_CPP_FRUVEG = Fruits and vegetables (annual data). Available at http://epp.eurostat.ec.europa.eu/extraction/evalight/EVAlight.jsp?A=1&language=en&root=/theme5/apro/apro_cpp_fruveg.
Gibbons, M., 1999. Science's new social contract with society. Nature 402 (6761), C81–C84.
GM Science Review Report, 2003. An open review of the science relevant to GM crops and food based on the interests and concerns of the public. First Report. Prepared by the GM Science Review Panel, UK. Available at http://www.gmsciencedebate.org.uk/report/default.htm#first.
Goeschl, T., Swanson, T., 2003. The development impact of genetic use restriction technologies: a forecast based on the hybrid crop experience. Environment and Development Economics 8, 149–165.
Kloppenburg, J.R., 2004. First the Seed: the Political Economy of Plant Biotechnology: 1942 to 2000. University of Wisconsin Press, Madison.
Lacy, W.B., Glenna, L., Biscotti, D. and Welsh, R., in press. Agricultural biotechnology, socioeconomic effects, and the fourth criterion. In: A. Seidel (Editor), Wiley Encyclopedia of Industrial Biotechnology.
Lheureux, K., Libeau-Dulos, M., Nilsagård, H., Cerezo, E.R., Menrad, K., Menrad, M. and Vorgrimler, D., 2003. Review of GMOs under research and development and in the pipeline in Europe. Technical Report. Available at http://ipts.jrc.ec.europa.eu/publications/pub.cfm?prs=1091.
Marris, C., Wynne, B., Simmons, P., Weldon, S., 2001. Public perceptions of agricultural biotechnologies in Europe. Final Report of the PABE Research Project. Available at http://csec.lancs.ac.uk/pabe/docs.htm.
Metcalfe, S., 1995. The economic foundation of technology policy: equilibrium and evolutionary perspectives. In: Stoneman, P. (Ed.), Handbook of the Economics of Innovations and Technological Change. InBlackwell, Oxford, pp. 409–512.
Newberg, J.A., Dunn, R.L., 2002. Keeping secrets in the campus lab: law, values and rules of engagement for industry–university R&D partnerships. American Business Law Journal 39 (2), 187–240.
Pistorius, R., van Wijk, J., 1999. The Exploitation of Plant Genetic Information: Political Strategies in Crop Development. CABI Publishing, Wallingford.
Pray, C.E., Umali-Deininger, D., 1998. The private sector in agricultural research systems: will it fill the gap? World Development 26 (6), 1127–1148.
Purdue News, 2002. (April 18) Terminator Tussle: Controversial Technology Needed, Experts Say. http://news.uns.purdue.edu/UNS/html4ever/020418.Thompson.terminator.html.
Ruttan, V.W., Hayami, Y., 1984. Towards a theory of induced institutional innovation. The Journal of Development Studies 20 (4), 203–223.
Shorett, P., Rabinow, P., Billings, P.R., 2003. The changing norms of the life sciences. Nature Biotechnology 21 (2), 123–126.
Srinivasan, C.S., Thirtle, C., 2003. Potential economic impacts of terminator technologies: policy implications for developing countries. Environment and Development Economics 8, 187–205.
Van Wijk, J., 2004. Terminating piracy or legitimate seed saving? The use of copy-protection technology in seeds. Technology Analysis & Strategic Management 16 (1), 121–141.
Vatn, A., 2002. Efficient or fair: ethical paradoxes in environmental policy. In: Bromley, D.W., Paavola, J. (Eds.), Economics, Ethics and Environmental Policy: Contested Choices. InBlackwell, Oxford, pp. 148–163.
Vatn, A., 2005. Institutions and the Environment. Edward Elgar, Cheltenham.
Welsh, R., Glenna, L., 2006. Considering the role of the university in conducting research on agri-biotechnology. Social Studies of Science 36, 929–942.

# Paper III

*Environment and Planning C: Government and Policy* 2008, volume 26, pages 968 – 981

doi:10.1068/c05116s

# Regulating the release of GMOs: contrasts between the European Union and Norway

**Valborg Kvakkestad, Arild Vatn**
Department of Economics and Resource Management, The Norwegian University of Life Sciences 5 (UMB), PO Box 5003, NO 1432 As, Norway;
e-mail: valborg.kvakkestad@umb.no, arild.vatn@umb.no
Received 18 April 2005; in revised form 9 October 2007

**Abstract.** The European Union (EU) and Norway have assessed the release of genetically modified organisms as commercial products quite differently. Of twenty-four notifications approved by the EU, Norway has approved four, rejected ten, and has ten pending. We analyse whether these differences could be explained by different value judgments. Three aspects of the formulation and implementation of the regulations are discussed: the effects to be prevented and encouraged, response to uncertainty and ignorance, and the burden of proof necessary. Norwegian rejections are found to be explicable by the combination of no real benefit to society, lack of scientific knowledge, and involved risks. EU approvals are based upon seeing no reason to believe that there will be any adverse effects on health and the environment. We conclude that problems arise when value conflicts are understood and treated solely as technical issues, as normal in the EU.

## 1 Introduction

A feature of the modern world is the rapid development of new technologies that potentially could have great impacts on humans and their interaction with the environment. Novel technologies often bring novel risks, which are difficult or impossible to predict and so involve strong uncertainty. An important challenge is how to build institutions that are suitable for making policy decisions concerning the development and use of these new technologies (Vatn, 2005). Traditionally, technology regulation has intended to tackle harm once it has become evident (Bodansky, 1994). During the last decades we have, however, observed a gradual change to regulations that involve an assessment prior to market placement with the aim of avoiding harm.

A new technology that is regulated worldwide by prior assessments is genetically modified organisms (GMOs) (Nap et al, 2003). Governance structures, however, differ widely between nations concerning how the release of GMOs into the environment is assessed (Strand, 2001). The European Union (EU) has, for example, adopted a process-based system while the USA uses a product-based regulation. These forms represent two distinct approaches (Busch, 2002). A process-based regulation implies that GMOs are regulated separately from other organisms, while a product-based regulation implies no distinction from other organisms. Major differences also exist between regions, such as the EU and Norway, that have adopted a process-based regulation regarding which GMOs are approved for release into the environment. For example, scientific risk assessment is predominant in the EU while Norwegian legislation also includes other aspects such as the benefits to society and sustainability. Hence, deciding which GMOs should be released is neither self-evident nor only a factual matter.

The release of GMOs is characterised by massive uncertainties. Sarewitz (2004) points out that, when we are dealing with complex systems, science will be unable to develop a coherent unified picture of 'the environment' that everyone can agree on. We see this in the case of genetically modified (GM) crops where some scientists emphasise

potential irreversible impacts and lack of predictability while others emphasise potential benefits and that the environmental issues raised do not differ qualitatively from conventional crops (Kvakkestad et al, 2007). Fundamentally, the situation of strong uncertainties implies that the fact–value distinction is particularly challenged and that specific value issues dominate (Kasanmoentalib, 1996).

Debates over values can be seen in terms of the consequences which are advanced as relevant, to be avoided, or to be encouraged. Which effects the regulation should prevent and encourage is not self-evident. Important issues concern whether the assessment process should only concern physical effects or whether it should also include more socioeconomic effects and deontological considerations.

Judgments have to be made on the predictability of consequences when deciding which GMOs should be released. Knight (1921) made an important distinction between risk and uncertainty in the way that risk implies known outcomes with known probabilities, while uncertainty means known outcomes but unknown probabilities. A situation where even the outcomes are unknown is defined as ignorance. Uncertainty and ignorance can be both reducible and irreducible. Reducible uncertainty and ignorance can be abridged by producing more scientific knowledge, while irreducible uncertainty and ignorance can not (Faber et al, 1996). Judgments on which of these categories of incertitude[1] are considered will influence the decisions made on GMO release. This will involve factual judgments on whether uncertainty and ignorance are present, and value judgments on how to deal with these categories of incertitude.

An important implication of uncertainty and ignorance is that value judgments on how the burden of proof should be framed become crucial for decisions on GMO release (Lemons, 1998). Proving harm to prove safety may be impossible. However, this depends on whether safety/harm should be generally proven or whether it is reduced to specific tests that the GMO in question have (no) adverse effects on $x$, $y$, and $z$ within time-frame $t$. In the latter case, the kind of research design that is accepted becomes crucial. Another important issue is whether the notifiers (companies wishing to release GMOs) themselves or the public authorities should provide evidence. Notifiers have strong incentives for proving safety but not harm, while one would expect public authorities to be more impartial.

We compare the legislation and its implementation in the EU and Norway regarding the release of GMOs as commercial products where the authorities operate under different legislative systems. We analyse how value judgments have influenced the official decisions regarding release of GMOs, and specifically consider which effects should be avoided and encouraged, how one should respond to uncertainty and ignorance, and the burden of proof. The paper is organised as follows. Section 2 describes the methods and data used. Section 3 examines the legal framework for release of GMOs within the EU and Norway. Section 4 examines how the legal provisions in the EU and Norway are implemented. In section 5 we discuss whether the differences between the decisions made on GMOs in the EU and Norway are explained mainly by differences in the legal framework or in the implementation of the legal framework. Finally, we discuss why raising particular value judgments matters for the regulation and release of GMOs.

## 2 Methodology and data

The methods used are analyses of public documents and interviews with civil servants in the European Commission and Norway. The public documents include legal text and their preparatory work as well as the decisions made. The public documents

[1] The term incertitude is used as a collective term for risk, uncertainty, and ignorance.

provided insufficient information for our analysis and were therefore supplemented with semistructured interviews. The Norwegian civil servants who were interviewed are Casper Linnestad,[2] Jan Husby,[3] and Beate Berglund Ekeberg.[4] Also, one civil servant[5] in the European Commission was interviewed. These interviewees are, respectively, coded n1, n2, n3, and ec1.

## 3 The legal framework for release of GMOs

The EU legislation on the release of GMOs has been in place since 1990, when the EU adopted the Deliberate Release Directive (DRD) 90/220/EEC (EC, 1990). The placing on the market of products containing or consisting of GMOs had to be licensed under this directive. Notifications were first submitted to one of the member states (MSs), which then became the rapporteur that should evaluate the notification. If the rapporteur MS reached a favourable opinion, and all the other MSs agreed, then the rapporteur MS issued a marketing consent that applied across the EU. If an objection was raised and maintained, the issue was transferred to a comitology procedure at the EU level. This procedure made the European Commission the final seat of real decision-making authority.

The comitology procedure consisted of a regulatory committee composed of representatives from the MSs that was chaired by the Commission. The Commission drafted a Commission decision that was forwarded to the committee to decide based on a qualified majority vote. If the proposal from the Commission differed from the opinion of the committee, or if no opinion was delivered, the Commission submitted the proposal to the European Council, who could either pass it by qualified majority, or reject it by unanimous decision. If the Council rejected the proposal, the Commission had to reexamine it. If the Council neither adopted the proposal nor indicated its opposition to it, the proposal was adopted by the Commission. In 1997 the Commission established a procedure for consulting scientific committees for their opinion on the release if objections were raised by MSs. This directive contained a safeguard clause that allowed an MS to provisionally restrict or prohibit the use of a GMO that had been authorised EU wide if the MS had justifiable reasons. The MS had to inform the Commission and other MSs of the reasons for its actions, and the Commission then used the comitology procedure to decide whether the restrictions were justified.

In the second half of the 1990s, when public protests against GMOs increased, the DRD received increasing criticism (Rosendal, 2005). A de facto moratorium on the release of GMOs as commercial products in the EU was established. As a response to this, a revised version of the DRD—Directive 2001/18/EC—was adopted in 2001 (EC, 2001). The basic procedures for the approval of GMOs are similar to the old DRD, except that the Council can oppose a draft Commission decision by qualified majority and that the Commission is formally required to consult the European Food Safety Authority (EFSA) if objections are raised and maintained.

Another regulation (EC) 1829/2003 on GM Food and Feed entered into force in 2003. This made possible application for the authorisation of release of GMOs into the environment—in accordance with the criteria established by the new DRD—if one of the uses of this GMO concerns food or feed. Currently, no GMOs are approved for release into the environment under this regulation.

[2] Senior advisor in The Norwegian Biotechnology Advisory Board (Oslo). Interviewed 4 July 2006.

[3] Former senior advisor in The Directorate for Nature Management (Trondheim). Interviewed 3 August 2006.

[4] Senior advisor in The Ministry of the Environment (Oslo). Interviewed 20 June 2006.

[5] This civil servant preferred to be anonymous. Interviewed 11 August 2006.

Norway became a member of the European Economic Area (EEA) in 1992 and the DRD was therefore enforced in Norway. However, as part of the EEA agreement, the safeguard clause was replaced by a provision that entitled the Norwegian Parliament the right to develop a more comprehensive legislative framework and thereby to permanently restrict or prohibit a GMO that had been authorised EU wide for other reasons than those laid down in the DRD. The additional act was termed the Gene Technology Act (GTA) and was adopted in 1993. The GTA was adjusted to the new DRD in 2006, when the original provision of the GTA for impact assessment was replaced by a new provision.

The Norwegian government is guided by advice from national professional bodies and the Norwegian Biotechnology Advisory Board. This board is an independent body appointed by the Norwegian government. The members of the board are selected such that technical, stakeholder, and public considerations should be present (n1). The national professional bodies are subordinated to different ministries and they are established to provide professional capacity for the ministries.

### 3.1 Which effects should be prevented and encouraged?

The DRDs state that those who want to release GMOs into the environment have to submit a notification that contains a prior case-by-case risk assessment of health and environmental effects. The old DRD was unclear on which kind of health and environmental consequences should be avoided. It was moreover unclear whether so-called indirect effects should be incorporated in the assessment. While direct effects are those that are a result of the GMO itself, indirect effects occur via mechanisms such as interactions with other organisms or changes in agricultural practice. The new DRD emphasises that direct and indirect, immediate and delayed, as well as potentially cumulative long-term effects should be assessed. The DRDs do not require that ethical or socioeconomic issues are included in the risk-assessment process. The new DRD does, however, include provisions for consulting ethical committees on matters of a general nature and for periodic reporting on the socioeconomic implications of the decisions made.

Since the DRD had to be enforced in Norway, the GTA contained almost the same (unclear) provisions for which health and environmental effects should be assessed as those in the old DRD, and they were replaced with similar provisions as those in the new DRD when the GTA was adjusted in 2006. In addition to health and environmental effects, the GTA also requires that effects on sustainable development, benefits to society, as well as whether the production and use will take place in an ethically and socially justifiable way should be evaluated (Gene Technology Act, 1993). 'Sustainable development' is specified to include long-term environmental effects, fair distributions in a global perspective, and the application of the precautionary principle (MoE, 1992). Benefit to society implies that other interests than those of the applicants and purely economic interests must be assessed. The provision for assessing what is ethically and socially justifiable, aims to ensure that modern biotechnology is utilised for the common good and in accordance with what is defined are Christian–humanistic values (MoE, 1992).

### 3.2 Response to uncertainty and ignorance

The response to uncertainty and ignorance varies between the three regulations. The old DRD does not require that uncertainty and ignorance should be considered, while it is required in the new DRD that the overall uncertainty for each risk that is identified has to be described. The preparatory work of the GTA emphasises that the precautionary principle should apply to the assessment. It is emphasised that

"in instances where a concrete assessment indicates that there may be reasonable doubt about the risk, this directs against such use" (MoE, 1992, page 46).[6]

When the new DRD was instituted, the EU also included the precautionary principle. The Commission issued a communication on the use of the precautionary principle in 2000 (EC, 2000). This document rejected some of the more absolutist interpretations of the principle by linking its use to the proportionality principle and the use of cost–benefit analysis. Similar interpretations are not found in the GTA or its preparatory work. Also, while the Norwegian regulations emphasise that the existence of uncertainty and ignorance directs against approval, the new DRD is unclear on this.

The new DRD responds to uncertainty and ignorance by requiring postmarket monitoring and time-limited approvals. The postmarket monitoring requirements include case-specific monitoring and general surveillance. Case-specific monitoring involves a more extensive and targeted monitoring than general surveillance and is not required if the risk assessment identifies an absence of risk or negligible risk. The meaning of negligible risk is, however, undefined. Prior to the adoption of the new provision of the GTA for impact assessment in 2006, the GTA laid down that postmarket monitoring could be required and that market consent could be time limited. The new provision of the GTA contains the same requirements for monitoring and time-limited approvals as the new DRD.

Although the new DRD and the GTA respond to incertitude, it is unclear whether they respond to irreducible uncertainty and ignorance. Requirements for postmarket monitoring and time-limited consent are only a response to reducible incertitude. The identification of the overall uncertainty for each risk and the application of the precautionary principle might be a response to irreducible incertitude.

### 3.3 Burden of proof

Whether safety or harm should be proven is unclear in all of the regulations. The DRDs and the GTA state that consent should be given only after making clear that the release will be safe for human health and the environment. However, the new DRD and the new provision for impact assessment of the GTA also state that the objective of the risk assessment is to identify and evaluate potential adverse effects of the GMO. Hence, both legal texts require that safety and harm should be proven. All of the regulations are unclear about the kind of evidence that is acceptable, although the criteria for evidence are more stringent in the new DRD and the GTA than in the old DRD.

In the DRDs the notifiers produce the risk assessment, which finally should be examined by the authorities. This is also the general procedure in Norway. However, the Norwegian authorities can also require that this is done by others (MoE, 1992). The postmarket monitoring provisions under the new DRD and the GTA lay down that the notifier should undertake monitoring.

## 4 The implementation of regulations on GMOs

A total number of thirty-four notifications for placing GMOs on the EU/EEA market have been submitted under the old DRD and thirty notifications have been submitted under the new DRD. Table 1 shows the decisions made on these notifications in the EU and Norway. During the period when the old DRD was in force, the EU approved slightly more than half of the thirty-four notifications, while Norway approved only four. No notifications were rejected in the EU, while ten notifications were rejected in Norway. After the new DRD entered into force, six notifications were approved in the EU,

[6] The original source is in Norwegian. We have used the same translation as The Norwegian Biotechnology Advisory Board (2003).

**Table 1.** The decisions made on the notifications received in the European Union and Norway (source: DfNM, 2001; EC, 2006a; JRC, 2007).

| Status of submitted notifications | Old DRD | New DRD | Gene Technology Act | |
|---|---|---|---|---|
| | | | the period when the old DRD was in force | the period after the new DRD entered into force |
| Approved | 18 | 6 | 4 | 0 |
| Rejected | 0 | 0 | 10 | 0 |
| Pending | 13 | 7 | 17 | 13 |
| Notifications withdrawn | 3 | 9 | 3 | 9 |
| Notifications transferred to Regulation 1829/2003 | – | 8 | – | 8 |

Note: DRD is the Deliberate Release Directive.

while none was approved in Norway. For the notifications which were pending under the old DRD, one has been approved under the new DRD, two are pending under the new DRD, one has been withdrawn, five have been transferred to Regulation 1829/2003, and four have not been updated to the requirements in the new DRD (BioTIK, 2006; DfNM, 2001; EC, 2006a; JRC, 2007).

Our analysis concentrates on the twenty-four notifications where a decision has been made—that is, those approved in the EU—and the decisions made on these notifications in Norway. We compare the Norwegian decisions with the decision made by the rapporteur MS in the cases where all the other MSs agreed and with the Commission decisions in the cases where MSs disagreed. For the Commission decisions we also report on the objections raised by dissenting MSs which were not accepted. Table 2 presents the characteristics of the twenty-four EU approvals and the Norwegian decisions on these notifications. Both the EU and Norway have approved three carnation lines and one tobacco line. Added to that, the EU has also approved six oilseed rape lines, eight maize lines, one chicory line, three vaccines, one milk test, and one soybean line. Most of the notifications approved under the old DRD were for cultivation, while none of the notifications that are approved under the new DRD is for cultivation. Notification number 24 under the new DRD did originally also cover cultivation, but this was rejected by the rapporteur MS (EFSA, 2005a). Cultivation was therefore taken out of the notification.

The carnation notifications are the only ones where no objections were raised by other MSs within the EU. Fourteen notifications under the old DRD were authorised by a Commission decision following a qualified majority vote in the Regulatory Committee (EC, 2003). However, in the case of approval number 8, the Regulatory Committee was unable to reach a qualified majority. The Commission then forwarded the matter to the Council, which was unable to pass it by qualified majority, or to reject it by unanimous decision. As a result the Commission made the final decision.

The Commission also made the final decision in all the six notifications that were approved under the new DRD. In these cases the Regulatory Committee was unable to reach a qualified majority and the Council neither adopted the proposed measures nor indicated its opposition to them by a qualified majority. Owing to the way the voting procedure is set up, in some of the decisions the Commission has decided against a majority of the MSs (ec1).

**Table 2.** The twenty-four European Union approvals and the Norwegian decisions on these (source: BioTIK, 2006; DfNM, 2001; EC, 2006a, 2006c; JRC, 2007).

| Approval number | Product | Application | Safeguard clause invoked by | Norwegian decision |
|---|---|---|---|---|
| 1 | Vaccine | Vaccine against Aujeszky's disease | | Rejected |
| 2 | Vaccine | Vaccine against rabies | | Rejected |
| 3 | Tobacco (H) | C | | Approved |
| 4 | Vaccine | Vaccine against Aujeszky's disease | | Rejected |
| 5 | Oilseed rape (hybrid system, H, A) | C | France | Rejected |
| 6 | Soybean (H) | I&P | | Pending |
| 7 | Chicory (male sterility, H, A) | C | | Rejected |
| 8 | Maize (I, H, A) | I&C | Austria Luxembourg Germany | Rejected |
| 9[a] | Oilseed rape (hybrid system, H, A) | I&C | | Rejected |
| 10[a] | Oilseed rape (hybrid system, H, A) | I&C | | Rejected |
| 11 | Milk test (A) | Antibiotic residues test in milk | | Rejected |
| 12 | Carnation (altered flower colour) | C | | Approved |
| 13 | Oilseed rape (H, A) | I&C | France Greece | Rejected |
| 14 | Maize (H) | I&C | Austria UK | Pending |
| 15 | Maize (I) | I&C | Austria Hungary | Pending |
| 16 | Maize (I, H) | I&P | | Pending |
| 17 | Carnation (altered flower colour) | C | | Approved |
| 18 | Carnation (increased flower colour) | C | | Approved |
| 18 | Carnation (increased vase life) | C | | Approved |
| 19[b] | Maize (H) | I&P | | Pending |
| 20[b] | Maize (I, A) | I&P | | Pending |
| 21[b] | Oilseed rape (H) | I&P | | Pending |
| 22[b] | Maize (I, H) | I&P | | Pending |
| 23[b] | Maize (I, A) | I&P | | Pending |
| 24[b] | Oilseed rape (hybrid system, H) | I&P | | Pending |

Notes: A is antibiotic resistance marker, C is cultivation, H is herbicide-tolerant, I&C is import and cultivation, I&P is import and processing, I is insect resistant.
[a] Not finally approved by the rapporteur member state.
[b] Approved under the new Deliberate Release Directive.

### 4.1 Which effects are prevented and which are encouraged?

The health and environmental effects that were assessed under the old DRD included only those that were a result of the GMO itself (EC, 1993; 1994a; 1994b; 1996a; 1996b; 1996c; 1997a; 1997b; 1997c; 1997d; 1998a; 1998b; 1998c; 1998d). No effects that could result from subsequent changes in agricultural practice were included. In the approvals

it was concluded that there is no reason to believe that there will be any adverse effects. Identified effects were defined to be unlikely or unproblematic. The spread of herbicide tolerance genes was considered unproblematic as it can be controlled by cultivation and nonselective herbicides (EC, 1996a; SCP, 1998a; 1998b). Antibiotic resistance genes as markers were not considered to cause harm (SCP, 1998a; 1998c). Some MSs disagreed on these conclusions. Concerns raised by dissenting MSs included potential effects of the inserted insect-resistance gene, the inserted herbicide tolerance gene, and the inserted antibiotic resistance marker (EC, 1996a; FMHCP, 1996; SBA, 1996a; 1996b).

For the notifications that are approved under the new DRD, the consequences that are assessed are quite similar to those that were assessed under the old DRD (EC, 2004a; 2005a; 2005b; 2005c; 2006b; 2007). None of these approvals concerned cultivation and the additional requirements in the new DRD therefore did become less relevant. The overall conclusion in the decisions was that the examination discloses no reason to believe that the placing on the market of the GMOs will adversely affect human or animal health or the environment. Two of the GMOs that are approved under the new DRD contain antibiotic resistance markers. These approvals concluded that the use of this gene is safe since use of this antibiotic in human and veterinary medicine is limited. The retention of the antibiotic-resistance gene was, however, rejected by dissenting MSs (EFSA, 2004a; 2005b). Dissenting MSs also requested more comprehensive environmental-risk assessments of unintended release (EFSA, 2004a; 2004b; 2005a; 2005b).

Cultivation was taken out of notification number 24 (herbicide-tolerant oilseed rape), since the rapporteur MS rejected cultivation. The rapporteur MS concluded that a loss of biodiversity due to the use of the associated herbicide could occur, that the dissemination of pollen could lead to gene flow to neighbouring oilseed rape fields and related wild relatives, and that effective and practicable measures minimising gene flow were undefined (FPS, 2004).

Ethical and socioeconomic concerns have been excluded in the risk assessments under the DRDs. Socioeconomic implications of the new DRD have, however, been evaluated in a report from the Commission (EC, 2004b). The socioeconomic concerns that are raised include the possibility that the EU regulatory framework may have an adverse impact on producers in developing countries, coexistence between GM-crops and other crops, and the possibility of a decrease in scientific activity and loss of competitiveness.

The Norwegian authorities have assessed effects on health and the environment separately from effects on sustainable development and benefit to society. The health and environmental effects that are evaluated are similar to those evaluated in the EU. They are, however, evaluated differently—that is, in the rejections it is concluded that health and/or environmental consequences are uncertain or that adverse environmental or health effects might occur. Four of the rejections concerned GMOs that would not be cultivated, either because they were unsuitable for the Norwegian climate or because the application concerned only import and processing. In these four rejections the only adverse health and environmental effect identified was from antibiotic-resistance marker genes. For the four products approved, the GMOs were concluded to imply no health or environmental risks (MoE, 2000a; 2000b; 2000c).

When evaluating sustainable development, the Norwegian authorities have considered a broader range of environmental effects, including global environmental effects. The assessments do, therefore, include effects on sustainable development in countries that might cultivate GMOs for export to Norway. For the rejections, the overall conclusion was either that the release would not contribute to sustainable development

or that it is unclear whether it would do so (MoE, 2001). It was emphasised that the GMOs would not contribute to a fair distribution from a global perspective. For the herbicide-tolerant GMOs, it was emphasised that these GMOs may result in the use of less harmful herbicides and reduced herbicide use. Nevertheless, they placed more weight on the argument that the introduction of herbicide-tolerant crops in the long run may impede the evolution of nonherbicide weed-management strategies. They stressed that often the same interests that develop herbicide-tolerant crops also produce the herbicide and that such interests can delay the development of a more environmentally friendly agriculture (MoE, 2001). The Norwegian carnation approvals concluded that the product, while not in conflict with sustainable development, was also unsuitable for promoting sustainable development (MoE, 2000a; 2000b; 2000c). In the tobacco case, the authorities doubted that herbicide tolerance would be in accordance with sustainable development. Since tobacco is unsuitable for growing in Norway, it was nevertheless approved.

The overall conclusion (also for the approved products) made by the Norwegian authorities on the GMO's benefit to society was that they fail to represent a societal benefit (MoE, 2000a; 2000b; 2000c; 2001). The authorities emphasised that the problems that GMOs are designed to solve do not exist in Norway or that the GMOs are insignificantly better than already existing products. In some cases it was emphasised that the GMOs are unsuitable for cultivation in Norway. We observe that the conclusive criterion in the Norwegian decisions has been whether health and environmental risks might be involved. However, this does not mean that considerations for sustainable development and benefit to society have been unimportant for the Norwegian decisions. In the rejections the reasoning has rather been that, since there is no benefit to society and no contribution to sustainable development, we should not accept the involved health and environmental risks.

### 4.2 Response to uncertainty and ignorance

None of the assessments made prior to the approvals under the old DRD explicitly considers or acknowledges uncertainty or ignorance (EC, 1996b; 1996c; 1997a; 1997b; 1997c; 1997d; 1998a; 1998b; 1998c; 1998d). Some of the dissenting MSs did, however, emphasise uncertainty concerning long-term environmental consequences (EC, 1996a; FMHCP, 1996; SBA, 1996a; 1996b). Similarly, the assessments made prior to the approvals for import and processing under the new DRD hardly consider or acknowledge uncertainty and ignorance (EC, 2004a; 2005a; 2005b; 2005c; 2006b; 2007). The approvals required no case-specific monitoring and the general surveillance plans that are approved offer limited possibilities for identifying unanticipated effects. The dissenting MSs emphasised that the provided monitoring plans were insufficient (EFSA, 2004a; 2004b; 2005a; 2005b). The rapporteur MS that decided to reject cultivation in the case of notification number 24 acknowledged cultivation-related uncertainty and ignorance.

The Norwegian rejections made reference to the precautionary principle, uncertainty, and lack of scientific knowledge. An example of a typical overall conclusion is:

> "Due to the risk and lack of scientific knowledge on possible effects for health and the environment, the deliberate release of this line in Norway would conflict with the precautionary principle ..." (DfNM, 1999, page 1).

Hence, the authorities considered and acknowledged reducible uncertainty and ignorance. In the three carnation approvals the authorities only acknowledged risk. They implicitly concluded that no uncertainty or ignorance was involved.

### 4.3 Burden of proof

When it is concluded in the EU decisions that there is no reason to believe that there will be any adverse effects, it seems as if safety has been proven. However, what has

happened is that the notifiers have provided certain tests or studies which failed to identify certain harmful effects. The EU authorities have defined these studies to be sufficient for approving the GMOs. Dissenting MSs have, however, found the studies to be insufficient for several of the approvals (EC, 1996a; EFSA, 2004a; 2004b; 2005a; 2005b; FMHCP, 1996; SBA, 1996a).

The Norwegian authorities have followed the same burden of proof procedure as the EU authorities. However, for the Norwegian rejections the authorities were critical of the tests presented by the notifier. First, Norwegian authorities emphasised that, where potential effects were deemed in need of assessment, by both the EU and Norway, tests were inadequate. Moreover, the Norwegian authorities emphasised that they wanted tests of effects that the EU considered irrelevant. In the case of the tobacco approval, it is unclear whether the authorities accepted the studies presented or whether they accepted the notification because the crop is not likely to be grown in Norway. For the carnation approvals, the studies were accepted.

## 5 Discussion

### 5.1 Legal framework or implementation?

The differences between the EU and Norwegian decisions can be explained by judgments made in the formulation of regulatory documents and their implementation. The scope that exists in the DRDs on which environmental and health effects should be prevented imply that the EU could have made similar conclusions as Norway on these issues. We can therefore not exclude the possibility that the EU had rejected some of the same notifications as Norway due to harm on health or the environment if the DRDs had been implemented differently. The notifications that have been rejected in Norway would probably have been rejected also if only health and environment were considered (n1 and n2). Possible explanations for the observed differences on the response to uncertainty and ignorance include differences both in the regulations themselves and in the implementation. While the GTA contains stronger requirements for uncertainty and ignorance to be considered and handled than the DRDs, the DRDs also provide scope for judgments on these issues and this scope has been used permissively. The DRDs restrict inclusion of sustainable development and benefit to society in the assessments preventing a similar emphasis on these issues in the EU. Austria's concern that the Austrian public is against GMOs is, for example, not an objection given the frame of the directive (ec1). EU decisions may have differed from the current EU decisions if these aspects had been included in the provisions of the DRDs (ec1).

We observe that the regulation of the release of GMOs in the EU and Norway differ more in the implementation of the regulatory documents than seems to follow from the regulatory documents themselves. The scope for judgment has been used by Norwegian regulators and their expert advisors to make quite restrictive decisions (n1 and n3), while this scope has been used by the EU regulators and their expert advisors to make quite permissive decisions. We also observe that the differences between the two DRDs are greater for the regulatory documents than for their implementation.

### 5.2 Why does it matter that particular value judgments arise?

So far, we have concluded that different judgments—made in the formulation of regulatory documents and the implementation of these documents—are crucial for the final decisions on whether or not to approve GMOs for release. That judgments are made or that they differ between the EU and Norway is unproblematic in itself. Decisions made on GMOs are political decisions and one of the important roles for politicians is exactly to make judgments. However, what could be problematic is if

these value judgments are treated as technical issues and are conducted by experts. Science fails to offer guidance in situations of ignorance since the issue becomes what chances we are prepared to take (Vatn, 2005).

Until 1997 decisions on the release of GMOs were mainly treated as a technical issue in the EU (Millstone, 2006). From 1997 the distinction between 'assessment of risk' on the one hand, and 'management of risk' on the other hand was emphasised within the EU. Risk assessment constitutes the first phase of the decision-making procedure. In this phase, scientific data is meant to be sought and combined as objectively as possible by scientific committees. It was assumed that risk assessment could be separated from values and interests. Risk management is then the second phase, where politicians in the regulatory committee, the Commission and the Council make trade-offs between risks and other considerations. However, despite this emphasis on the role of politicians in the decision-making procedure, in fact, the advice from the EU-level experts has been extremely important for actual decisions. This is the case also after 1997. In the cases where the EU-level expert advisors have concluded that they cannot find any risks to human health or the environment (which has always been the case), the Commission had no other choice than to conclude with approval in the draft Commission decisions since the DRDs lay down that the only relevant reason for rejecting a GMO notification is the risk to human health and the environment. In the case that the EU-level experts conclude that there are risks to human health and the environment, the procedure does, however, leave more room for the politicians. Hence, even though the EU has established a procedure where value issues should be decided upon by politicians, we observe that several value issues are decided on by experts—for example, what kind of effects should be avoided, whether to consider uncertainty and ignorance, and what kind of evidence is accepted.

The Norwegian decision-making procedure has, to a greater extent, treated decisions on the release of GMOs as a value issue. Value issues relating to the benefits to society and sustainable development are mainly treated as such since the Biotechnology Advisory Board has a particular responsibility for this, while value issues related to human health and the environment are also partly treated as technical issues. Experts employed in national professional bodies in Norway are responsible for providing advice on health and environmental effects and they have been making value judgments on the acceptability of harm to health and environment, response to uncertainty and ignorance, as well as which evidence is acceptable. The Biotechnology Advisory Board and the national professional bodies present proposals for the final decision on whether to approve a GMO. The government is, however, unbounded by these proposals or other expert advice.

## 6 Conclusions

The consequences of releasing GMOs are difficult or impossible to predict. This situation of extreme uncertainty implies that making a clear distinction between facts and values is also impossible. Moreover, specific value issues arise. In this paper we have seen that value judgments regarding response to uncertainty and ignorance, burden of proof, and which effects should be prevented and encouraged are important for decisions on GMO release. Perhaps most important are the consequences that are assessed and what kind of documentation from the notifiers is accepted. It is the combination of no real benefit to society, lack of scientific knowledge, and involved risks that explain the Norwegian rejections, while the main explanation for the EU approvals is that they see no reason to believe that there will be any adverse effects on health and the environment.

The problem here is not that value judgments may differ. What is problematic is when procedures are such that value judgments are treated as technical issues conducted by experts. We think that modern societies are now in a phase of trying to adapt to 'a new reality'—that more and more decisions concern situations characterised by uncertainty and ignorance. That is, a challenge to standard expert-based risk-assessment procedures. We observe that countries have reacted differently to these challenges in the case of GMOs and that the solutions chosen often must be characterised as confused or inconsistent. Certainly, the Norwegian regulation seems to have been more sensitive to these matters. However, Norway has also found emphasising the value aspects easier since few economic stakes are involved.

Our civilization has just started a journey on the road to clarifying what uncertainty and ignorance might imply for our future regulatory practices concerning new technologies. In that respect, learning from past cases is important for building the necessary capacity for reflection and adaptation in technological assessment processes.

**Acknowledgements.** We are grateful to Clive Spash and two anonymous referees for their constructive feedback on our manuscript. Helpful comments from Anne Ingeborg Myhr on earlier versions are also gratefully acknowledged.

**References**

BioTIK, 2006, "Oversigt over alle gensplejsede varetyper, der må sælges på det danske marked" [Overview of all genetically modified products that can be marketed in Denmark], The National Consumer Agency of Denmark, BioTIK-secretariat, http://www.biotik.dk/myndigheder/varer_oversigt/

Bodansky D, 1994, "The precautionary principle in US environmental law", in *Interpreting the Precautionary Principle* Eds T O'Ridon, J Cameron (Earthscan, London) pp 203 – 228

Busch L, 2002, "The homiletics of risk" *Journal of Agricultural and Environmental Ethics* **15** 17 – 29

DfNM, 1999, "Genetically modified maize line Bt176 approved for marketing pursuant to council directive 90/220 EEC. Basis for the Norwegian decision to prohibit marketing", Directorate for Nature Management, Trondheim

DfNM, 2001, "Genmodifiserte produkter som er søkt omsatt i EU/EØS under direktiv 90/220 EØF pr. 13.07.2001" [Marketing notifications on genetically modified products in EU/EEA under Directive 90/220 EEC, 13 July 2001], Directorate for Nature Management, Trondheim, http://www.dirnat.no/multimedia.ap?id=31808

EC, European Commission, Brussels

1990, "Council Directive of 23 April 1990 on the deliberate release into the environment of genetically modified organisms (90/220/EEC)" *Official Journal of the European Communities* **L117** 15 – 27 (8 May)

1993, "Commission Decision 93/572/EEC of 19 October 1993" *Official Journal of the European Communities* **L276** 16 – 17 (9 November)

1994a, "Commission Decision 94/385/EC of 8 June 1994" *Official Journal of the European Communities* **L176** 23 – 24 (9 July)

1994b, "Commission Decision 94/505/EC of 18 July 1994" *Official Journal of the European Communities* **L203** 22 – 23 (6 August)

1996a, "Commission Decision 96/158/EC of 6 February 1996" *Official Journal of the European Communities* **L037** 30 – 31 (15 February)

1996b, "Commission Decision 96/424/EC of 20 May 1996" *Official Journal of the European Communities* **L175** 25 – 26 13 July

1996c, "Commission Decision 96/281/EC of 3 April 1996" *Official Journal of the European Communities* **L107** 10 – 11 (30 April)

1997a, "Commission Decision 97/98/EC of 23 January 1997" *Official Journal of the European Communities* **L031** 69 – 70 (1 February)

1997b, "Commission Decision 97/392/EC of 6 June 1997" *Official Journal of the European Communities* **L164** 38 – 39 (21 June)

1997c, "Commission Decision 97/393/EC of 6 June 1997" *Official Journal of the European Communities* **L164** 40 – 41 (21 June)

1997d, "Commission Decision 97/549/EC of 14 July 1997" *Official Journal of the European Communities L225* 34 (15 August)

1998a, "Commission Decision 98/294/EC of 22 April 1998" *Official Journal of the European Communities* **L131** 33 (5 May)
1998b, "Commission Decision 98/291/EC of 22 April 1998" *Official Journal of the European Communities* **L131** 26 – 27 (5 May)
1998c, "Commission Decision 98/293/EC of 22 April 1998" *Official Journal of the European Communities* **L131** 30 – 31 (5 May)
1998d, "Commission Decision 98/292/EC of 22 April 1998" *Official Journal of the European Communities* **L131** 28 – 29 5 May
2000, "Communication from the Commission on the precautionary principle", http://ec.europa.eu/dgs/health_consumer/library/pub/pub07_en.pdf
2001, "Directive 2001/18/EC of the European Parliament and of the Council on the deliberate release into the environment of genetically modified organisms and repealing Council Directive 90/220/EEC" *Official Journal of the European Communities* **L106** 1 – 38 (17 April)
2003, "Questions and answers on the regulation of GMOs in the European Union", European Commission, MEMO/03/196 (9 October), http://europa.eu/rapid/pressReleasesAction.do?reference=MEMO/03/196&format=HTML&aged=∅&language=EN&guiLanguage=en
2004a, "Commission Decision 2004/643/EC of 19 July 2004" *Official Journal of the European Union* **L295** 35 – 37 (18 September)
2004b, "Report from the Commission to the Council and the European Parliament on the experience of member states with GMOs placed on the market under Directive 2001/18/EC", http://ec.europa.eu/environment/biotechnology/pdf/com_575_final.pdf
2005a, "Commission Decision 2005/608/EC of 8 August 2005" *Official Journal of the European Union* **L207** 17 – 19 (10 August)
2005b, "Commission Decision 2005/635/EC of 31 August 2005" *Official Journal of the European Union* **L228** 11 – 13 (3 September)
2005c, "Commission Decision 2005/772/EC of 3 November 2005" *Official Journal of the European Union* **L291** 42 – 44 5 November
2006a, "Questions and answers on the regulation of GMOs in the European Union", European Commission, MEMO/06/58 (6 February), http://europa.eu/rapid/pressReleasesAction.do?reference=MEMO/06/58&format=HTML&aged=∅&language=EN&guiLanguage=en
2006b, "Commission Decision 2006/47/EC of 16 January 2006" *Official Journal of the European Union* **L26** 17 – 19 31 January
2006c, "EU policy on biotechnology", European Commission, Directorate General Environment, http://ec.europa.eu/environment/biotechnology/pdf/eu_policy_biotechnology.pdf
2007, "Commission Decision 2007/232/EC of 26 March 2007" *Official Journal of the European Union* **L100** 20 – 24 (17 April)

EFSA, European Food Safety Authority
2004a, "Opinion of the Scientific Panel on Genetically Modified Organisms on a request from the Commission related to the Notification (Reference C/DE/02/9) for the placing on the market of insect protected genetically modified maize" *The EFSA Journal* **49** 1 – 25
2004b, "Opinion of the Scientific Panel on Genetically Modified Organisms on a request from the Commission related to the Notification (Reference C/NL/98/11) for the placing on the market of herbicide-tolerant oilseed rape" *The EFSA Journal* **29** 1 – 19
2005a, "Opinion of the Scientific Panel on Genetically Modified Organisms on a request from the Commission related to the Notification (Reference C/BE/96/01) for the placing on the market of glufosinate-tolerant hybrid oilseed rape" *The EFSA Journal* **281** 1 – 23
2005b, "Opinion of the Scientific Panel on Genetically Modified Organisms on a request from the Commission related to the Notification (Reference C/DE/02/9) for the placing on the market of insect-protected genetically modified maize" *The EFSA Journal* **251** 1 – 22

Faber M, Manstetten R, Proops J, 1996 *Ecological Economics: Concepts and Methods* (Edward Elgar, Cheltenham, Glos)

FMHCP, 1996, "Reasons for objections(s) raised under Directive 90/220/EEC", letter to the EC (9 August), Federal Ministry for Health and Consumer Protection, Vienna

FPS, 2004 *Statement of the Belgian Competent Authority* letter to the EC (2 February), Federal Public Service of Public Health, Food Chain Safety and Environment, Brussels

Gene Technology Act, 1993, "Lov om framstilling og bruk av genmodifiserte organismer (genteknologiloven) [The act relating to the production and use of genetically modified organisms], Act no. 38 (2 April), Ministry of the Environment, Oslo

JRC, 2007, "Deliberate releases and placing on the EU market of genetically modified organisms (GMOs)", Joint Research Centre of the European Commission, http://gmoinfo.jrc.it/gmc_browse.aspx?DossClass=0

Kasanmoentalib S, 1996, "Science and values in risk assessment: the case of deliberate release of genetically engineered organisms" *Journal of Agricultural and Environmental Ethics* **9** 42 – 60

Knight F V, 1921 *Risk, Uncertainty and Profit* (Houghton Mifflin, Boston, MA)

Kvakkestad V, Gillund F, Kjøllberg K A, Vatn A, 2007, "Scientists' perspectives on the deliberate release of GM-crops" *Environmental Values* **16** 79 – 104

Lemons J, 1998, "Burden of proof requirements and environmental sustainability: science, public policy, and ethics", in *Ecological Sustainability and Integrity: Concept and Approaches* Eds J Lemons, L Westra, R Goodland (Kluwer Academic, London) pp 75 – 103

Millstone E, 2006, "Can food safety policy-making be both scientifically and democratically legitimated? If so, how?" in *Ethics and the Politics of Food* Eds M Kaiser, M Lien (Wageningen Academic Publishers, Wageningen) pp 36 – 47

MoE, Ministry of the Environment, Oslo

1992, "Ot.prp.nr. 8 (1992 – 1993)" [Proposition from the larger division of the Norwegian parliament no. 8 (1992 – 1993)]

2000a, "Tillatelse til omsetning av genmodifisert nellik linje 959A, 988A, 1226A, 1351A, 1363A og 1400A" [Marketing approval of genetically modified carnation line 959A, 988A, 1226A, 1351A, 1363A and 1400A]

2000b, "Tillatelse til omsetning av genmodifisert nellik linje 4, 11, 15 og 16" [Marketing approval of genetically modified carnation line 4, 11, 15 and 16]

2000c, "Tillatelse til omsetning av genmodifisert nellik linje 66" [Marketing approval of genetically modified carnation line 66]

2001, "Begrunnelse for de norske forbudene mot omsetning av EU-godkjente genmodifiserte organismer" [Basis for the Norwegian decision to prohibit marketing of EU-approved genetically modified organisms], http://www.regjeringen.no/nb/dep/md/tema/Naturmangfold/Genteknologi-/Begrunnelse-for-de-norske-forbudene-mot-omsetning-av-EU-godkjente-genmodifiserte-organismer.html?id=411955

Nap J P, Metz P L J, Escaler M, Conner A J, 2003, "The release of genetically modified crops into the environment—Part I. Overview of current status and regulations" *Plant Journal* **33** 1 – 18

Norwegian Biotechnology Advisory Board, 2003, "Sustainability, benefit to the community and ethics in the assessment of genetically modified organisms. Implementation of the concepts set out in Section 1 and 10 of the Norwegian Gene Technology Act", discussion paper, Norwegian Biotechnology Advisory Board, http://www.bion.no/publikasjoner/sustainability.pdf

Rosendal K G, 2005, "Governing GMOs in the EU: a deviant case of environmental policy making?" *Global Environmental Politics* **5** 82 – 104

Sarewitz D, 2004, "How science makes environmental controversies worse" *Environmental Science and Policy* **7** 385 – 403

SBA, 1996a, "Reasons for objection(s) raised under Directive 90/220/EEC (notification no. C/F/95/12-02)", letter to the EC (9 August), Swedish Board of Agriculture, Jönköping

SBA, 1996b, "Reasons for objection(s) raised under Directive 90/220/EEC (notification no. C/F/95/12-07) ", letter to the EC (9 August), Swedish Board of Agriculture , Jönköping

SCP, Scientific Committee on Plants

1998a, "Opinion of the Scientific Committee on Plants regarding the genetically modified, glufosinate-tolerant rape notified by the Agrevo Company Scientific Committee on Plants", http://europa.eu.int/comm/food/fs/sc/scp/outcome_gmo_en.html

1998b, "Opinion of the Scientific Committee on Plants on the genetically modified maize lines notified by the Novartis Company", http://europa.eu.int/comm/food/fs/sc/scp/outcome_gmo_en.html

SCP, Scientific Committee on Plants

1998c, "Opinion of the Scientific Committee on Plants regarding 'Submission for placing on the market of glufosinate tolerant corns (Zea Mays) Transformation Event T25' by the Agrevo Company", http://europa.eu.int/comm/food/fs/sc/scp/outcome_gmo_en.html

Strand R, 2001, "The role of risk assessment in the governance of genetically modified organisms of agriculture" *Journal of Hazardous Materials* **86** 187 – 204

Vatn A, 2005 *Institutions and the Environment* (Edward Elgar, Cheltenham, Glos)

# Paper IV

# Governing uncertain and unknown effects of genetically modified crops[1]

Valborg Kvakkestad and Arild Vatn

**Abstract**

This paper analyzes the capabilities of three different governance regimes for adequately handling uncertain and unknown effects of genetically modified (GM) crops. Adequate handling requires the development of sound procedures for identification of uncertainty and ignorance (U&I), reduction of U&I, decisions on how to treat irreducible U&I and monitoring of unexpected effects. The nature of U&I implies, however, that these procedures will be highly incomplete. Governance mechanisms that facilitate cooperative adaptation and communicative rationality are therefore needed. The three governance regimes (GR) compared are: GM crops are produced by private firms and these firms are made liable for harm (GR1); GM crops are produced by private firms and the government decides whether the crops should be marketed (GR2); and GM crops are produced by public research organizations and the government decides whether the crops should be marketed (GR3). The effect of bringing the civil society into the decision-making process is also analyzed. GR3 will be stronger in cooperative adaptation and communicative rationality than GR2. Public research organizations have fewer conflicts of interest with the government than private firms, and academic norms are important as opposed to firms where commercial norms are important. Difficulties in proving harm and identifying the responsible firm will make GR1 weak in cooperative adaptation and communicative rationality.

**Keywords**

GM crops, institutions, uncertainty, ignorance, cooperative adaptation, communicative rationality

[1] A slightly revised version of this paper is published online in *Ecological Economics* (http://dx.doi.org/10.1016/j.ecolecon.2010.10.003).

# 1 Introduction

A feature of the modern world is the rapid development of new technologies that could potentially have great—and often irreversible—impacts on humans and their interaction with the natural environment. Novel technologies often bring novel risks, which are hard or impossible to predict. Genetically modified (GM) crops are an example of a new technology that has the potential to influence both society and ecosystems in a novel way. The genetic material of these crops has been altered using genetic engineering techniques. Use of GM crops is characterized by uncertainty, ignorance and potentially long time lags between the introduction of these crops and the possible appearance of harm (Wolfenbarger and Phifer, 2000). While some scientists emphasize potential irreversible impacts and lack of predictability, others emphasize potential benefits and argue that the environmental issues raised by growing GM crops do not differ qualitatively from those of conventional crops (Kvakkestad et al., 2007). An important challenge is how we can deal adequately with uncertainty and ignorance (U&I) in the case of GM crops. Similar issues are relevant for other technologies as well.

The challenges related to U&I can best be illustrated by identifying the differences between these concepts and risk. Risk implies known outcomes with known probabilities, whereas uncertainty means known outcomes but unknown probabilities. A situation where even the outcomes are unknown is defined as ignorance. Ignorance arises from many sources, including "incomplete knowledge, contradictory information, conceptual imprecision, divergent frames of reference and the intrinsic complexity or indeterminacy of many natural and social processes" (Stirling, 1998, page 103). A further central distinction is whether uncertainty and ignorance can be reduced by increasing scientific knowledge (Faber et al., 1996; Wynne, 1992). Uncertainty can be irreducible because of measurement problems (Spash, 2002), and ignorance can be irreducible because of complexity or indeterminacy in social-ecological processes and the incompleteness of scientific methods.

This paper undertakes a governance-oriented analysis on how to deal with U&I in relation to GM crops. Governance is about forming institutional structures, and is concerned with the different ways in which societies can organize themselves to accomplish their goals (de Loë et al., 2009). The chosen governance regime—which in

this study refers to institutions that determine who should be involved in the production, assessment, marketing decisions and monitoring of GM crops—will influence human motivations and which kind of considerations can or should be taken into account, and thereby our ability to handle uncertain and unknown effects of GM crops. The purpose of this paper is to analyze how three different governance regimes enable the decision maker(s) to deal with the uncertain and unknown harmful effects of GM crops on common-pool resources[2]. One way of dealing with the uncertain and unknown effects of GM crops is to generally stop the development of GM crops. This paper does however limit its focus to a situation where some GM crops might be desirable and some might not, and therefore they should be assessed case by case.

The paper is organized as follows. Section 2 first elaborates on which issues are important for adequate handling of U&I, and then presents an analytical framework for analyzing the capabilities of different governance regimes for handling these issues adequately. Finally, three possible institutional alternatives for dealing with U&I are identified. Section 3 analyzes the capabilities of these governance regimes for handling U&I. The three regimes are: (1) GM crops are produced by private firms and these firms are made liable for harm; (2) GM crops are produced by private firms and the government decides whether the crops should be marketed; and (3) GM crops are produced by public research organizations and the government decides whether the crops should be marketed. The effect of bringing the civil society into the decision-making process is also analyzed. In Section 4, we discuss and expand on the findings of Section 3. Section 5 offers a conclusion on the issues raised in this paper.

## 2 Important dimensions when designing institutions for U&I

### *2.1 Adequate handling of U&I—what are the challenges?*

An adequate way of dealing with U&I related to GM crops will demand institutional procedures that provide possibilities for preventing uncertain and unknown harmful

[2] Resources where processes are linked in webs and cycles of matter and energy, and where demarcation of specific parts or pieces is physically very difficult.

effects. Preventing harm is important when serious irreversible[3] harm may be involved, and preventing harm is often less costly than dealing with harm once it has become evident (Sunstein, 2008). Avoidance of uncertain and unknown harmful effects requires procedures for assessing U&I prior to marketing. These procedures should ensure that U&I is identified and reduced (if possible), and that sound decisions can be made on how to deal with irreducible U&I.

The process of reducing U&I might be a never-ending and very costly process, because it will always be possible to learn more about the consequences of GM crops. Reducing U&I might also imply irreversible harm. GM crop field trials are, for example, necessary to learn more about the environmental effects of GM crops, but this type of learning might itself cause irreversible harm. The governance regimes should therefore balance the importance of reducing reducible U&I against the costs. With irreducible U&I (and reducible U&I that is too costly to reduce), the governance regimes should ensure that uncertain and unknown harmful effects does not automatically imply that GM crops be banned, but rather that avoiding uncertain and unknown harmful effects should be balanced against other social needs.

Procedures for handling U&I should not only enable the prevention of harm, but also ensure satisfactory monitoring of uncertain and unknown harmful effects that might arise from the cultivation of GM crops. Monitoring cannot prevent harm, but it can limit the extent of the harm by making early warnings possible and enabling adjustments in the design of GM crops (Karlsson, 2003).

### *2.2 Which governance regimes are best suited for adequate handling of U&I? An analytical framework*

Markets, hierarchies and networks represent three alternative forms of governing transactions in the private sphere that shape the behavior and interests of individual actors (Powell, 1990). In the market, exchange is mediated through and made possible by the use of legally binding contracts. In hierarchies, authority plays an equivalent role. In networks, exchange is possible because actors trust each other (Hindmoor, 1998).

[3] In the sense that it is very costly or impossible to make restoration and/or goods that are incommensurable (qualitatively distinctive) are lost (Sunstein, 2008).

Williamson (1991; 1985) emphasizes that the cost of transferring different goods and services (transaction costs) varies according to asset specificity, uncertainty and frequency, and that different levels of these costs determine whether transactions will be governed by markets, hierarchies (firms) or some kind of hybrid forms. Transactions that involve uncertainty about their outcome and require substantial transaction-specific investments are more likely to take place within hierarchically organized firms than exchanges that are straightforward and do not require transaction-specific investments (Williamson, 1985). Sociologists have highlighted the prevalence and functionality of network forms of governance that represent a unique alternative possessing its own logic (Powell, 1990). Networks preserve greater diversity of search routines than hierarchies, and they convey richer, more complex information than the market (Podolny and Page, 1998). Ring and Van de Ven (1992) emphasize not only that managers will be motivated by efficiency considerations, but also that varying levels of risk and reliance on trust will explain whether markets, networks or hierarchies are the appropriate governance structures for transactions.

General theories on these different types of governance structures have been applied to public management (Marsh and Rhodes, 1992). Of particular interest for this paper is the emerging literature on environmental governance. Because the state is now involved as a core actor, the above concepts take on a somewhat different meaning. Mostert (2008) uses the terms hierarchies, markets and 'third alternatives'. Here, hierarchy means that the government assumes full responsibility for managing and regulating the use of environmental goods/bads. Market governance implies that public goods/bads are transformed into marketable goods by splitting them up into parts and privatizing them. An example of a third alternative is network management, which is based on the idea that government policy is made and implemented in policy networks. These networks consist of different governmental and nongovernmental actors, such as companies and NGOs. Lemos and Agrawal (2006) identify three idealized social mechanisms of environmental governance, namely state, market and community. Different hybrids between these mechanisms, like comanagement (between state agencies and communities), public–private partnerships (between state agencies and market actors) and private–social partnerships (between market actors and communities) are possible

and often desirable. de Loë et al. (2009) identify regulatory, market regulation, civil society, cooperative management and self-regulation as different generic models of environmental governance, and emphasize that environmental governance should involve forms of group decision making that accommodate diverse views, that hybrid partnerships among state and non-state actors are needed and that shared learning is critical.

Pure market governance is undesirable for the uncertain and unknown effects of GM crops because the environmental goods that GM crops might affect cannot easily be made into tradable objects. To limit the scope of this paper, we do not include pure network[4] governance in the analysis. The governance regimes that will be analyzed in this paper all rest, therefore, on some kind of hierarchical structure, in that the state establishes some kind of regulation for the handling of the uncertain and unknown effects of GM crops. Market actors and community actors will, however, be involved to varying degrees.

The nature of U&I implies that U&I regulations will be highly incomplete. It is impossible to develop ex ante instructions that specify in advance adequate responses to new information/knowledge, how U&I should be identified and reduced, how to make sound decisions in the case of irreducible U&I and how monitoring should be conducted. Asset specificity, i.e. that each GM crop is unique with respect to potential environmental effects, implies that it would be impossible to develop regulations that are adjusted to each GM crop variety. Further, we find ourselves in a situation of asymmetric information between the producers and the regulator because the producers are better informed about the GM crop that they have developed than the regulator.

Faced with incomplete regulations, and therefore situations where contingent events and countermove strategies are very difficult to foresee, governance mechanisms that facilitate cooperative adaptation and communicative rationality are needed. Cooperative adaptation refers to a capacity and predisposition toward responding to disturbances in a coordinated and compliant way (Williamson, 1999), while communicative rationality implies communication with the intention of reaching

[4] Pure network governance might be a feasible form of governing the uncertain and unknown effects of GM crops, but might also be problematic because of the lack of trust between state agencies, the GM industry and the civil society (Marris et al., 2001).

agreement exclusively via the force of better arguments (Habermas, 1984). The communications should be free from manipulation and coercion, and the participants should act on 'higher' motives than their own interests. The decisions that are made should also be competent, i.e. the best possible understanding and agreement should be constructed (Webler, 1995). Because it is impossible to establish ex ante regulations that specify adequate handling of U&I, cooperative adaptation and communicative rationality become important to 'fill out the ex post gaps' in the regulation adequately.

Williamson (1999) emphasizes that the efficient governance response to the need for cooperative adaptation is to provide contractual[5] safeguards or, if unmet needs for added coordination persist, to internalize the hazard through unified ownership/vertical integration. Vertical integration is the preferred solution when contractual hazards are high, i.e. "maladaption hazards will arise if one or both parties decline to cooperate" (Williamson, 1999, page 315). In such a setting, vertical integration can be necessary to ensure cooperative adaption. One of the key issues that will be analyzed in this paper is therefore whether (1) the state should produce, assess and monitor GM crops and decide whether GM crops should be marketed, or (2) firms should produce GM crops under some kind of U&I regulation that ensures that firms undertake the assessments, the marketing decisions and the monitoring in accordance with the will of the government. The effect of combining these two alternatives with involvement from the civil society will also be analyzed.

Cooperative adaptation and communicative rationality might seem to overlap somewhat. Important differences, however, are that while cooperative adaptation in this case is concerned with compliance with the will of the government, communicative rationality is concerned with how to reach the best possible decision. A governance regime that is strong in cooperative adaptation will not necessarily be strong in communicative rationality, and vice versa. Cooperative adaptation is positive for adequate handling of U&I only if the government favors adequate handling of U&I. The analysis in this paper assumes that this is the case. Another difference is that while

[5]Although the type of regulations that we study cannot be considered to be contracts (and not all aspects concerning the governance of U&I can be understood as transactions), many of the challenges with incomplete regulations are similar to the challenges with incomplete contracts. Both in the case of a regulation and a contract, the government actors and the contracting parties want to make sure that those that are regulated or the contracting party respond to disturbances in a coordinated and compliant way.

cooperative adaptation implies that the government gains access to the knowledge produced by the GM producers (i.e. no strategic use of asymmetric information), communicative rationality requires that the knowledge that is produced is freely available. Free access to knowledge is important for making complementary U&I assessment and monitoring approaches possible. Free allocation of knowledge will also make accumulation of knowledge possible.

Faced with incomplete regulations and the need for cooperative adaptation and communicative rationality, the motivations—interests and values—that are fostered by the governance regime become important. Public research should ideally serve public needs and intellectual inquiry (Caldart, 1983), firms should maximize profits, public regulatory bodies should serve the government and the civil society should articulate, foster and serve shared/public interests and values through dialogue and debate (Vatn, 2005). These goals are instituted via the forming of roles and other institutional structures that ensure that employees act in accordance with the goals. These roles shape, for example, what become the self-interests of the employees (O'Neill, 1998). Problems occur if the goals of an agent conflict with an adequate response to U&I and we are faced with incomplete regulations. In such a situation, we are likely to observe strategic use of asymmetric information, strategic interpretation of contractual ambiguities and lack of cooperative adaptation when net local advantages might be involved (Williamson, 1999).

# 3 The capability of three different governance regimes to handle U&I

## *3.1 The governance regimes to be analyzed*

The three alternative governance regimes analyzed in this paper are presented in Table 1. Governance regime (GR) 1 implies that GM crops are produced by private firms and that these firms are made liable for harm. A monitoring regulation is established that requires monitoring by the firm (GR1a) or monitoring by a public regulatory body (GR1b). Governance regime 2 implies that GM crops are produced by private firms and that the government decides whether the crop should be marketed. An assessment and monitoring regulation is established that requires assessment and monitoring by the firm (GR2a) or

assessment and monitoring by a public regulatory body (GR2b). Governance regime 3 implies that GM crops are produced by public research organizations and that the government decides whether the crop should be marketed. An assessment and monitoring regulation is established that requires monitoring by the public research organization (GR3a) or assessment and monitoring by a public regulatory body (GR3b). The effect of including network governance in terms of bringing the civil society or citizens into the decision-making process will also be analyzed. The three governance regimes are analyzed in relation to their ability to facilitate cooperative adaptation and communicative rationality.

**Table 1**
The characteristics of the three alternative governance regimes (GR) and their subregimes. PF: private firm; G: government; PRB: public regulatory body; PRO: public research organization

| | **GR 1**[1] | | | **GR 2**[2] | | | | | **GR 3**[2] | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **1a** | **1b** | | **2a** | | **2b** | | | **3a** | | **3b** | | |
| | PF | PF | PRB | PF | G | PF | PRB | G | PRO | G | PRO | PRB | G |
| Production | x | x | | x | | x | | | x | | x | | |
| U&I assessment prior to marketing | x | x | | x | | | x | | x | | | x | |
| Marketing decision | x | x | | | x | | | x | | x | | | x |
| Monitoring | x | | x | x | | | x | | x | | | x | |

[1]The firm is made liable for any potential unexpected effects. Regulation for monitoring is established.
[2]Regulation for U&I assessment and monitoring is established.

### *3.2 GR1: Making private firms liable for environmental harm*

Environmental liability refers to civil liability for personal injury and damage to goods and private property, as well as damage to the environment where private property does not exist (e.g. flora, fauna, land, air and water resources) (Winter et al., 2008). The latter case is most relevant for this paper and implies that the state makes the compensation claim. Both the EU[6] and the USA[7] have established liability to the wider environment.

[6] Directive on Environmental Liability with regard to the Prevention and Remedying of Environmental Damage.
[7] The Comprehensive Environmental Response, Compensation, and Liability Act.

The intended function of environmental liability is to create incentive to prevent[8] environmental harm in the future and to compensate victims by making firms fully responsible for all adverse environmental effects (Bally, 2005; Ulph and Valentini, 2004; Zweifel and Tyran, 1994). In principle, such a governance regime would be preferable because it is often the private firms that are most informed concerning their products and are therefore most competent in identifying U&I, reducing U&I and monitoring unexpected effects. If firms expected to bear all the costs of their activities, they would also be likely to make sound decisions in relation to irreducible U&I. It is, however, questionable whether it is possible to develop and enforce a regulation that ensures that the firms bear all the costs of their decisions, and thereby be strong in cooperative adaptation and communicative rationality.

To ensure that liability can provide firms with sufficient incentives to prevent environmental harm, it is important that well-defined obligations for risk are set up in advance (Baram, 1982; Farber 1991), i.e. that the agents know what kind of harm[9] they might be liable for, and that they know approximately how much compensation will be required for different types of harm. The nature of U&I will make it difficult to specify ex ante what kinds of unknown effects are unwanted, and how much compensation will be required for different types of harm.

Strict liability and negligence represent two different liability rules. Strict liability implies that the defendant is held liable for the harm caused whether or not the defendant acted negligently, while negligence implies that a plaintiff should be entitled to recover from a defendant who has caused harm only if the defendant failed to take reasonable steps to avoid inflicting the harm (Epstein, 1973). Ensuring full compensation under strict liability requires that actual harm is proven and that the responsible firm is identified. Under negligence, the plaintiff also needs to prove that the defendant had a duty to conform to a specific standard of conduct and that the defendant breached that duty (Bally, 2005). The complexity of the causal chains between crops and the environment, time lags between cause and effect, asymmetric information and damage caused by

[8] In terms of providing polluters with appropriate incentives to reduce the risk of environmental damage (i.e. to undertake safety measures that reduce expected damages) because of the cost implications of potential future liability.

[9] A prior complete enumeration of sanctionable actions is, however, not required.

multiple sources makes identification of harm, injurers, and proof of lack of due care by the injurer[10] difficult (Feess et al., 2009; Ulph and Valentini, 2004; Zweifel and Tyran, 1994). If, for example, a reduction in the number of birds is observed in an area where several types of GM crops are grown, it is difficult first to prove that the GM crops caused the damage and then to identify which of the GM crops caused the damage. The strength of the causal link between the damage and the activities that caused the damage that needs to be established is therefore important for what kind of incentives exist for avoiding harm (Bally, 2005). Costly proof of liability reduces the expected costs of risky behavior (Farber, 1991).

To facilitate the identification of harm and injurers, it is crucial that adequate procedures for monitoring are established. Unforeseen harm is especially difficult to identify because it is not known what kind of harm to search for. If firms monitor (GR1a), we are likely to be faced with incomplete regulations concerning what and how to monitor, as well as how to respond to any information obtained under monitoring. It is beneficial for the firm that research results that could potentially harm sales or benefit competitors are kept secret (O'Neill, 1998). It will not be in a firm's interest to identify harm or to make harm transparent, and we are therefore likely to observe strategic interpretation of ambiguities in regulations (Koch and Ashford, 2006). Involving public regulatory bodies in the monitoring (i.e. GR1b) is likely to reduce these problems because these bodies are more likely to be concerned with identifying and adequately handling harm. The public regulatory body will, however, be faced with asymmetric information concerning the GM crops that are grown, and the firm will be likely to use this asymmetric information strategically.

Assuming that damage is proven and that the responsible firm is identified, it will be uncertain whether damage will be compensated. Damage might not be compensated if the firm has insufficient assets to repair or compensate for the damage, or if the damage is identified after a firm has closed down, implying that the firms do not perceive themselves as having to bear the full costs of risky behavior (Ulph and Valentini, 2004). Hutchinson and van 't Veld (2005) emphasize that it is not uncommon for environmental damages to exceed the market value of the firm responsible for an accident. A

[10] In the case of negligence.

compulsory insurance scheme could ensure that compensation will be available and impose risk-reduction measures on firms (Merrifield, 2002). Environmental liability for GM crops does however raise insurability challenges (Dahlström et al., 2003). Firms tend to consider that low-probability risks are negligible, thus these risks are often ignored in loss-prevention and loss-protection decisions (Katzman, 1985). The very nature of U&I implies a lack of actuarial information to assess the probability and scale of adverse events, and thereby difficulties in adjusting premiums to effective risk (Zweifel and Tyran, 1994). The insurers might not be able to monitor the care level of their clients (Feess and Hege, 2000), and the insurers may become insolvent (Merrifield, 2002).

Whether insurance is possible does however depend on the type of liability that is established. Dahlström et al. (2003) emphasize that it is reasonably certain that insurers would have been unwilling to underwrite the unquantifiable risks of GM crops if strict liability had been required. Limited liability and restrictions that exclude liability if technology developers follow applicable regulations and operate on the basis of best available scientific knowledge will increase the likelihood that risks are insurable (Dahlström et al., 2003). The EU directive for environmental liability does for example emphasize that the polluter can be exempted from liability if those who caused environmental damage demonstrate that the damage was caused by activities or emissions authorized expressly by the competent authorities, or if it was not possible to anticipate the damaging effect on the basis of the state of scientific knowledge at the time, and if the operator was not negligent (European Commission, 2004). If more than 30 years have passed since the event that caused the damage, the directive will not apply (European Union, 2004).

If we assume not only that damage is proven and that the responsible firm is identified, but also that damage is compensated, this governance regime might still cause concern if possibilities for serious irreversible harm exist. Zandvoort (2005) emphasizes that liability can only lead to full internalization of external costs if these effects are reversible. For natural life-support systems, it is often the case that no practical substitutes are possible, and that compensation cannot therefore be meaningfully specified (Toman, 1994). Possibilities for serious irreversible harm might imply that

remediation is impossible or very costly, and that no amount of compensation could make the victim equally well off.

We observe that it is questionable whether this governance regime provides sufficient compensation and prevention in the case of the uncertain and unknown effects of GM crops on the wider environment. Difficulties concerning documenting harm and identifying who is responsible, as well as possibilities for insufficient firm assets to repair or compensate for possible damage imply that possible damage will not be fully compensated, and therefore that insufficient incentives exist for preventing uncertain and unknown harm. The difficulties in establishing well-defined behavior restrictions ex ante also imply insufficient preventive incentives. The possibilities for serious irreversible harm imply that prevention becomes important (Sunstein, 2008). This lack of sufficient preventive incentives implies that firms not will be motivated to act in accordance with the will of the government, and that they will not be motivated to produce a best possible understanding of the involved uncertainties. This is illustrated by the fact that the success of environmental liability laws in the USA has been heavily disputed (Schoemaker and Schoemaker, 1995). This critique does not imply that liability should play no role in the governance of U&I. Combining liability with other types of regulations might be preferable.

Integrating civil society into this governance regime might increase its ability to handle U&I. Tools such as participatory technology assessment could, for example, help the insurance sector gain a better understanding of the involved U&I and the harms that are important to avoid (Dahlström et al., 2003). If insurance is inapplicable, firms could be asked to facilitate participatory technology assessment. It is, however, important to be aware that conflicts of interest might arise when private firms are required to implement the outcomes from this type of technology assessment.

### *3.3 GR2: Government decision on marketing of GM crops that are produced privately*

This governance regime implies that firms that want to market a GM crop have to apply for approval from the government. A public regulatory body (GR2a) or the firm (GR2b) that has produced the crop becomes responsible for U&I assessment and monitoring. Hence, in addition to establishing monitoring procedures (as with GR1), the government

has to establish procedures for: (1) how U&I should be identified and reduced; (2) what is accepted as sufficient identification and reduction of U&I; and (3) how to make decisions on irreducible U&I. Developing regulations that specify sufficiently ex ante how these issues should be dealt with is almost impossible. Assessment and monitoring regulations are therefore likely to be highly incomplete, and therefore governance mechanisms that facilitate cooperative adaptation and communicative rationality are needed.

GR2b will be stronger in cooperative adaptation than GR2a because it is the public regulatory body that will assess U&I and monitor unexpected effects. Possibilities for strategic use of asymmetric information by the firm might, however, hamper the identification and reduction of U&I and the monitoring of unexpected effects.

The USA and the EU have established a regulatory framework that is quite similar to GR2b. This type of governance regime will be quite weak in cooperative adaptation and communicative rationality. A firm's interests when assessing U&I and monitoring unexpected effects would conflict with the interests of the government, therefore instead of being motivated to produce less uncertain GM crops with assessments and monitoring that provide the best possible understanding of the problem, the firm will be motivated to produce GM crops with assessments and monitoring that they expect to result in government approval. Nielsen (2006) emphasizes that no systematic or explicit approaches to minimizing conflicts of interest between the firm and the state are embedded in most current regulatory frameworks. The fact that the government will decide whether the GM crop should be approved does, however, provide some safeguards and some possibilities for communicative rationality in the decision on whether the GM crop should be marketed. However, the government might be faced with asymmetric information, and a fully competent decision is therefore unlikely.

How and by whom the politicians are advised under GR2 is important for the fostering of communicative rationality. Current practice implies that a panel of experts usually reviews the full proposals by the firm (Nap et al., 2003). The advice from the EU-level experts has, for example, been extremely important for actual EU decisions on the release of GM crops (Borrás, 2006; Kvakkestad and Vatn, 2008). In the cases where the EU-level expert advisors have concluded that they cannot find any risks to human health or the environment (which has always been the case), the Commission has no other

choice than to conclude with approval. A recent example is the approval of a genetically modified potato. Despite the fact that concerns have been raised about environmental uncertainty and its potential health effects because of the containment of antibiotic resistance marker genes, the European Food Safety Authority concluded that the product is unlikely to have an adverse effect on human and animal health or the environment and the European Commission therefore approved the release of the potato (European Union, 2010).

The independence of the expertise underlying decisions has been questioned, and it has been emphasized that it is not possible in practice to restrict the advisory process to technical issues, and that subjective values of scientists influence decision making (Jasanoff, 1990). A survey among GM scientists indicates that they hold opposing perspectives on the reasonability of releasing GM crops into the environment, and that these perspectives depend on disciplinary background and on whether or not they are industry funded (Kvakkestad et al., 2007). A crucial issue is therefore what types of institutions could promote the 'right' kind of behavior by experts and how to interrelate science and politics more explicitly. Millstone (2007) emphasizes that the policy makers should take democratically accountable responsibility for establishing explicit guiding principles for the deliberations of scientific policy advisors, and that scientific policy advisors should act explicitly in accordance with that guidance, for example by acknowledging explicitly the ethical and political assumptions that guided their scientific assessments. It is also important that the politicians are advised by scientists that represent different disciplines, because multiple perspectives can prevent the narrowing of alternatives (Jasanoff, 2002).

Several authors emphasize that when the stakes are high, values diverge, unknown effects might be involved and time scales are long, politicians should not be advised solely by scientific experts (e.g. Funtowicz and Ravetz, 1992; O'Connor and van den Hove, 2001). Ambiguity, i.e. disagreement about the significance of outcomes[11], implies that expert analytical methods are less applicable (Stirling et al., 2007). Including civil society participation might be important, because citizens tend to see problems, issues

[11] An example is that although there is general agreement that gene flow from GM crops occurs, there is disagreement about the harmfulness of gene flow from GM crops.

and solutions that experts do not see (Fiorino, 1990), and it should be acknowledged that scientific experts are not more competent than others in making value decisions. Hoffmann-Riem and Wynne (2002) emphasize that multiple interacting perspectives can be useful in identifying the limitations of the other perspectives, and that lay knowledge, in particular, can make a valuable addition to expert knowledge. How to articulate the roles of scientific experts and laypersons in democratic governance of uncertain risks has been a main concern in recent times. A suggested solution is increased citizen participation by consulting the civil society in the decision-making processes (Borrás, 2006). Consensus conferences, participatory technology assessment, citizen juries and public hearings are examples of this type of consultation. It is, however, important to be aware that involving civil society will not automatically make the decision-making process more communicative. In some cases, this type of involvement might instead aggravate conflict and foster more strategic behavior. Webler (1995) emphasizes that 'correct' participation requires multi-way communication, nonhierarchical participation, respect for individual autonomy and critical self-reflection.

GR2b is expected to imply more information for the public than GR2a because this sub-regime implies publicly based information not only from the assessment, but also from the monitoring. This, however, depends on what types of restrictions firms put on the information they submit to the authorities. Today, confidentiality is frequently claimed on the information used/produced in the assessment and the monitoring, and no incentive currently exists for companies to communicate unexpected or negative findings during GM crop development (Newell, 2003; Nielsen, 2006). It is also the case that users of GM crops must sign user agreements that forbid the use of the seeds for any independent research (Scientific American Magazine, 2009). Current practice therefore implies that free allocation of knowledge and independent research and monitoring are prevented.

### *3.4 GR3: Government decision on marketing of GM crops that are produced publicly*

This governance regime will make the research and development (R&D) of GM crops a public responsibility. In this way, the government will directly influence management objectives and the handling of U&I (Vatn, 2005). Public R&D of GM crops might seem a

radical alternative, but the fact is that between the 1930s and the 1970s the R&D of new plant varieties in the Western world was mainly conducted publicly (Pistorius and van Wijk, 1999). The setup of this governance regime is quite similar to GR2. Regulations for identification of U&I, reduction of U&I, monitoring of unexpected effects and handling of irreducible U&I will be established. The regulation would require public research organizations to submit information on the GM crop that they have developed. For the same reasons as for GR2, these regulations will be highly incomplete.

GR3 can be quite strong in cooperative adaptation and possibilities for communicative rationality because public research organizations have fewer conflicts of interest with the government than private firms, and because academic norms foster communicative rationality. These norms include Merton's five principles for good science, namely universalism, communalism, disinterestedness, organized skepticism and originality (Ziman, 1984). These norms have proved to be fruitful for an understanding of the interaction between psychological and institutional mechanisms in the production and communication of scientific knowledge (Weingart, 2004). In addition to these principles, the norm that public research should serve public needs is important (Caldart, 1983). Communalism implies that even though the government and the public regulatory body will face the same type of asymmetric information as under GR2, strategic use of this information by the public research organizations is less likely. The knowledge produced under this governance regime is more likely to be freely allocated to the public and other scientists than under the other two governance regimes.

Public research organizations will, however, not be perfect in cooperative adaptation and communicative rationality. Merton's idealized normative account of science has been shown to not always be an adequate description of scientific practice (Mulkay, 1979). Competitive pressure in public science has led to secrecy, and sometimes dogmatic commitment, which does not fit with fully organized skepticism. Disciplinary boundaries make it difficult to bring together the broadest possible set of research tools (Jasanoff, 2002; Kriebel et al., 2001), and the subjective values of scientists tend to influence scientific outcomes (Jasanoff, 1990). Although those that develop GM crops possess valuable knowledge about the product, they also tend to be 'too close' to the product they have developed (Fjelland, 1999). Conflicts of interest might arise if the

approval of a GM crop could benefit the public research organizations. We therefore expect GR3b to have stronger possibilities for communicative rationality and cooperative adaptation than GR3a.

The validity of these conclusions depends, however, on how the government is advised (see Section 3.3) and how public R&D of GM crops is organized. A crucial issue is what kind of institutional structures would be the most likely to ensure that public research organizations fulfill their roles as the guardians of the 'general interest' in the case of highly complex and uncertain issues that imply social and political controversies. More multidisciplinary research might be important. It is also suggested that citizens should be actively involved in the production, control and validation of public science and technology (for a review, see Bäckstrand, 2003; Borrás, 2006; Hage et al., 2010). This is, however, a controversial issue, because scientific quality might not be consistent with public participation in the production of science and technology.

# 4 Discussion

## *4.1 Comparison of the three governance regimes*

Table 2 presents how we expect the three governance regimes to perform on the criteria identified in Section 2, which are important for identification and reduction of U&I, monitoring of unexpected effects and sound decisions on irreducible U&I. The first criterion, cooperative adaptation, concerns compliance with the will of the government by the GM producers. Cooperative adaptation is important when the producers[12] must provide information to the government and the public regulatory body, and when the U&I assessment, the marketing decision and the monitoring must be conducted by the producers of GM crops or the public regulatory body. Cooperative adaptation is, however, irrelevant for the marketing decision when the government makes this decision.

The second criterion, possibilities for communicative rationality, is important in the U&I assessment, the marketing decision and the monitoring. Information for the

[12] To simplify the analysis, we have not analyzed cooperative adaptation between the public regulatory body and the government.

public is important to provide possibilities for civil society to take part in the handling of U&I. There is a strong connection between the two criteria, and the success of one criterion depends on the success of the other. Lack of cooperative adaptation and thereby strategic use of asymmetric information could, for example, reduce the possibilities for communicative rationality and competent decisions. Because conflicting interests with the government's will to handle U&I adequately also reduce the possibilities for communicative rationality, it follows that a governance regime that is strong in cooperative adaptation will also provide strong possibilities for communicative rationality.

**Table 2**
The three governance regimes and their capacity for adequate handling of U&I. PF: private firm; G: government; PRB: public regulatory body; PRO: public research organization

| Criterion | | Governance regime | | | | | |
|---|---|---|---|---|---|---|---|
| | | (1) PF produces GM crops and is made liable for harm | | (2) PF produces GM crops and G decides on marketing | | (3) PRO produces GM crops and G decides on marketing | |
| | | 1a (monitoring by PF) | 1b (monitoring by PRB) | 2a (monitoring and assessment by PF) | 2b (monitoring and assessment by PRB) | 3a (monitoring and assessment by PRO) | 3b (monitoring and assessment by PRB) |
| 1. Cooperative adaptation | Information to G/PRB | + | + | + | + | + + | + + |
| | U&I assessment | + | + + | + + | + + + + | + + + | + + + + |
| | Marketing decision | + | + + | Irrelevant | Irrelevant | Irrelevant | Irrelevant |
| | Monitoring | + | + + + | + | + + + | + + | + + + |
| 2. Potential for communicative rationality | Information to the public | + | + + | ++ | + + + | + + + + | + + + + |
| | U&I assessment | + | + + | + + | + + + | + + + | + + + + |
| | Marketing decision | + | + + | + + + | + + + | + + + + | + + + + |
| | Monitoring | + | + + | + | + + | + + | + + + |

Notes: + ranks the governance regimes on an ordinal scale for each criterion. The more +, the more likely it is that this governance regime will be strong on this criterion. Rankings should not be compared across criteria.

GR3b is likely to be the governance regime that handles U&I most adequately. U&I assessment and monitoring by a public regulatory body and marketing decisions by the government will provide possibilities for cooperative adaptation and communicative rationality. Public research organizations will probably provide most of the information that is needed by the public regulatory body and the government. The governance regimes that will probably be second best in the handling of U&I are GR3a and GR2b. The public research organization (GR3a) will probably be imperfect in cooperative adaptation and somewhat weaker in possibilities for communicative rationality than the public regulatory body. Private production of GM crops (GR2b) implies possibilities for strategic use of asymmetric information and therefore reduced possibilities for communicative rationality in the U&I assessment, the marketing decision and the monitoring. GR2a and GR1b will probably be third best in adequate handling of U&I. Both will be stronger in cooperative adaptation than GR1a because the firms might experience the government not approving their products (for GR2a) or being made liable for harm (for GR1b). An advantage of GR2a compared with GR1b is that it provides greater possibility for preventing harm because the government will decide which GM crops should be marketed. A disadvantage of GR2, however, might be that it shifts much of the responsibility for unexpected hazards arising from these products onto the state (Dahlström et al., 2003). GR1a will probably be the governance regime that handles U&I least adequately. This regime will be weak in cooperative adaptation and communicative rationality because monitoring by the firm makes it less likely that it will expect to be made liable for harm that might occur. Integrating the civil society into the decision-making process could be important for fostering communicative rationality.

Our analysis is based on ideal types of state, market and civil society. In recent decades, however, we have seen a blurring of society's stable categorizations (Gibbons, 1999). University research is more market oriented, private funding of university research has become more common, and universities are permitted to retain intellectual property rights to publicly funded inventions (Newberg and Dunn, 2002; Shorett et al., 2003). Firms are no longer only responsible to private interests, but are increasingly regulated by the state and are also increasingly owned by 'the society'. In the last decade, for example, we have seen a substantial increase in corporate social responsibility reports (Wilenius,

2005)[13]. Finally, governments are increasingly also becoming market actors. States have become shareholders, and are involved in bond issues. This type of blurring implies that the difference between the governance regimes to the right in Table 2 compared with those to the left might be less than in the case of ideal types of actors. It is, however, important to be aware that even though the boundaries are blurred, there still "remains a fundamental difference between entities aimed at improving human welfare and those with a fiduciary responsibility to shareholders" (Stone, 2002, page 616). March and Olsen (1995) also emphasize that governance takes place partly by the creation of the identities of public officials. By reformulating these identities, it is possible to institute 'taking public office' as something different from 'taking private office'.

It is also important to be aware that the analysis in this paper assumes that the government favors adequate handling of U&I. Governments will, of course, not always search for the policy that is most preferable. 'Internalities' and private goals (Wolf, 1979) might imply that only some parts of the government favor adequate handling of U&I. Well-designed systems for exchange may often be more consistent with modern realities than are dreams of reasoned discussion (March and Olsen, 1995). Governments that have a weak relationship with civil society may have less will to handle U&I adequately (Vatn, 2005). If governments do not intend to ensure adequate handling of U&I or see no importance in it, communicative rationality becomes more important and cooperative adaptation (with the will of the government) becomes less important.

Finally, it is important to be aware that the three governance regimes vary concerning the distribution of costs and benefits. GR2b, for example, implies that public money is used for assessing and monitoring GM crops. A fairer solution might be that some tax revenue is created for firms, destined to the assessment and monitoring of GM crops. GR3 can be unfair if public money is used for developing GM crops, public money is used for assessing them, and then those crops bring benefits to private firms. An important issue, which requires further research, is therefore how GM crops developed by

[13] Wilenius (2005) does however emphasize that only a small minority of the business world really have sustainability in their core values, and even fewer are those companies that really put their values and principles into action. Clapp (2008) emphasizes that in the case of illegal GM crop release, corporate social responsibility has proven extremely weak.

public research can be distributed to the private sector. A possible solution might be that they are sold through some kind of auction system.

### *4.2 Other important issues when designing governance regimes for GM crops*

Several issues other than avoiding the uncertain and unknown effects of GM crops are important when designing institutions for deciding which GM crops should be used. A wider focus, such as providing the society with adequate means of guiding GM crop development in directions desirable for the society as a whole, is necessary. An obvious issue that should be included is whether the GM crop will cause known harm. The public has, however, also been concerned about several other aspects related to GM crops, such as the dominance of multinational corporations, the ownership of the technology and how the use of GM crops might affect agriculture, and many do not see any real social benefits from this technology (Marris et al., 2001). Institutions for GM crops should allow the assessment of such issues, and enable evaluation of whether this technology will contribute to a preferable society and whether this technology is the best solution to the targeted problems (Helland, 2009). Including considerations for social benefits of GM crops, identifying what values and interests are served and determining whether the production and use will take place in an ethical and socially justifiable way might be important. It might, for example, be more reasonable to accept the possibility of unexpected harm if the GM crop has the potential to create important societal benefits than if this is not the case. It is important that institutions for decision making on the use of GM crops enable a balancing of the trade-off between preventing uncertain and unknown effects and stimulating investment in socially valuable activities that, for example, could be important for employment (Feess et al., 2009). An example might be that the 30-year limit to liability that is established in the EU might be a reasonable balance between establishing preventive measures and promoting socially valuable activities.

Enabling overall societal assessments requires that the regulation that is established allows such assessments. Methods that could be used include cost–benefit analysis, multicriteria analysis, and less structured methods such as consensus conferences and citizen juries.

## 5 Conclusion

Our paper provides insights into how the choice of governance regimes for GM crops might influence our ability to handle the uncertain and unknown environmental harmful effects of GM crops. To secure adequate handling of U&I, it is important that the governance regime provides possibilities for preventing harm. A procedure for identifying U&I, reducing U&I (if possible) and making sound decisions on irreducible U&I prior to the environmental release of GM crops is needed. If a GM crop is released into the environment, it is important that early warnings are made possible by procedures for monitoring unexpected effects. However, the nature of U&I implies that these procedures will be highly incomplete and will provide possibilities for the strategic use of asymmetric information and strategic interpretation of regulatory ambiguities. Governance mechanisms that facilitate cooperative adaptation and communicative rationality are therefore proposed.

The governance regimes that are compared in this paper in relation to their ability to handle U&I are as follows.

1. GM crops are produced by private firms and these firms are made liable for harm. A monitoring regulation is established that requires monitoring by the firm (GR1a) or monitoring by a public regulatory body (GR1b).
2. GM crops are produced by private firms and the government decides whether the crop should be marketed. An assessment and monitoring regulation is established that requires assessment and monitoring by the firm (GR2a) or assessment and monitoring by a public regulatory body (GR2b).
3. GM crops are produced by public research organizations and the government decides whether the crop should be marketed. An assessment and monitoring regulation is established that requires assessment and monitoring by the public research organization (GR3a) or assessment and monitoring by a public regulatory body (GR3b).

It is likely that GR3b will handle U&I most adequately, followed by GR3a or GR2b; next are GR2a or GR1b, and finally GR1a. Firms are mainly responsible to private interests, whereas public research organizations have a duty to the state and the general public. Public research organizations therefore have fewer conflicts of interest with the

regulatory body and the government than private firms, and will be stronger in cooperative adaptation than private firms. The importance of academic norms in public research organizations versus the importance of commercial norms in firms also implies that public research organizations will be stronger in communicative rationality than private firms. Difficulties in proving harm and identifying the responsible firm will make liability regimes weak in cooperative adaptation and communicative rationality. Assessment and monitoring of U&I by a public regulatory body and marketing decision making by the government will reduce the possibilities of a lack of cooperative adaptation and provide stronger possibilities for communicative rationality compared with assessment, marketing decision making and monitoring by firms or public research organizations.

To ensure that GR3 will facilitate adequate handling of U&I, it is important that communicative rationality is fostered in the government, the public regulatory body and the public research organizations. Reversing the commercialization of public research and including civil society in the public decision-making process are important in that respect.

**Acknowledgments**

We are grateful to four anonymous referees for their constructive and helpful feedback on this manuscript.

## 6 References

Bally, J., 2005. Recent developments in the field of international liability regimes to tackle environmental risks. Water Science & Technology 52 (6), 51–57.

Baram, M.S., 1982. Alternatives to Regulations. Heath, Lexington, MA.

Bäckstrand, K., 2003. Civic science for sustainability: reframing the role of experts, policy-makers and citizens in environmental governance. Global Environmental Politics 3(4), 24–41.

Borrás, S., 2006. Legitimate governance of risk at the EU level? The case of genetically modified organisms. Technological Forecasting & Social Change 73, 61–75.

Caldart, C.C., 1983. Industry investment in university research. Science, Technology & Human Values 8 (2), 24–32.

Clapp, J., 2008. Illegal GMO releases and corporate responsibility: questioning the effectiveness of voluntary measures. Ecological Economics 66, 348–358.

Dahlström, K., Skea, J., Stahel, W.R., 2003. Innovation, insurability and sustainable development: sharing risk management between insures and the state. The Geneva Papers on Risk and Insurance 28 (3), 394–412.

de Loë, R.C., Armitage, D., Plummer, R., Davidson, S., Moraru, L. 2009. From Government to Governance: A State-of-the-Art Review of Environmental Governance. Final Report. Prepared for Alberta Environment, Environmental Stewardship, Environmental Relations. Rob de Loë Consulting Services, Guelph.

Epstein, R.A., 1973. A theory of strict liability. Journal of Legal Studies 2, 151–204.

European Commission, 2004. Questions and Answers Environmental Liability Directive. European Commission MEMO 04/78, April 1, Brussels.

European Union, 2004. Directive 2004/35/CE of the European Parliament and of the Council of 21 April 2004 on environmental liability with regard to the prevention and remedying of environmental damage. Official Journal of the European Union L 143, 56–75.

European Union, 2010. Commission Decision of 2 March 2010 concerning the placing on the market, in accordance with Directive 2001/18/EC of the European Parliament and of the Council, of a potato product genetically modified for enhanced content of the amylopectin component of starch. Official Journal of the European Union L 53, 1114–75.

Faber, M., Manstetten, R., Proops, J., 1996. Ecological Economics: Concepts and Methods. Edward Elgar, Cheltenham.

Farber, S., 1991. Regulatory schemes and self-protective environmental risk control: a comparison of insurance, liability, and deposit / refund systems. Ecological Economics 3, 213–245.

Feess, E., Hege, U., 2000. Environmental harm and financial responsibility. The Geneva Papers on Risk and Insurance 25 (2), 203–217.

Feess, E., Muehlheusser, G., Wohlschlegel, A., 2009. Environmental liability under uncertain causation. European Journal of Law and Economics 28 (2), 133–148.

Fiorino, D.J., 1990. Citizen participation and environmental risk: a survey of institutional mechanisms. Science, Technology and Human Values 15 (2), 226–243.

Fjelland, R., 1999. Vitenskap mellom sikkerhet og usikkerhet [Science between Certainty and Uncertainty]. Ad Notam Gyldendal, Oslo.

Funtowicz, S.O., Ravetz, J.R., 1992. Three types of risk assessment and the emergence of post-normal science, in: Krimsky, S., Golding, D. (Eds.), Social Theories of Risk. Praeger, London, pp. 251–273.

Gibbons, M., 1999. Science's new social contract with society. Nature 402 (6761), C81–C84.

Habermas, J., 1984. The Theory of Communicative Action. Vol I: Reason and the Rationalization of Society. Beacon Press, Boston, MA.

Hage, M., Leroy, P., Petersen, A.C., 2010. Stakeholder participation in environmental knowledge production. Futures 42, 254–264.

Helland, A., 2009. Dealing with uncertainty and pursuing superior technology options in risk management – The inherency risk analysis. Journal of Hazardous Materials 164, 995–1003.

Hindmoor, A., 1998. The importance of being trusted: transaction costs and policy network theory. Public Administration 76, 25–43.

Hoffmann-Riem, H., Wynne, B., 2002. In risk assessment, one has to admit ignorance. Nature 416, 123.

Hutchinson, E., van 't Veld, K., 2005. Extended liability for environmental accidents: what you see is what you get. Journal of Environmental Economics and Management 49, 157–173.

Jasanoff, S., 1990. The Fifth Branch: Science Advisors as Policy-Makers. Harvard University Press, Cambridge, MA.

Jasanoff, S., 2002. The life sciences and the rule of law. Journal of Molecular Biology 319, 891–899.

Karlsson, M., 2003. Biosafety principles for GMOs in the context of sustainable development. International Journal of Sustainable Development and World Ecology 10, 15–26.

Katzman, M.T., 1985. Chemical Catastrophes: Regulating Environmental Risk through Pollution Liability Insurance. Richard D. Irwin, Homewood, IL.

Koch, L., Ashford, N.A., 2006. Rethinking the role of information in chemicals policy: implications for TSCA and REACH. Journal of Cleaner Production 14 (1), 31–46.

Kriebel, D., Tickner, J., Epstein, P., Lemons, J., Levins, R., Loechler, E.L., Quinn, M., Rudel, R., Schettler, T., Stoto, M., 2001. The precautionary principle in environmental science. Environmental Health Perspectives 109 (9), 871–876.

Kvakkestad, V., Gillund, F., Kjølberg, K.A., Vatn, A., 2007. Scientists' perspectives on the deliberate release of GM-crops. Environmental Values 16, 79–104.

Kvakkestad, V., Vatn, A., 2008. Regulating the release of GMOs: contrasts between the European Union and Norway. Environment and Planning C: Government and Policy 26, 968–981.

Lemos, M.C., Agrawal, A., 2006. Environmental governance. Annual Review of Environment and Resources 31, 297–325.

March, J.G., Olsen, J.P., 1995. Democratic Governance. The Free Press, New York.

Marris, C., Wynne, B., Simmons, P., Weldon, S., 2001. Public perceptions of agricultural biotechnologies in Europe. Final Report of the PABE Research Project. Available at http://csec.lancs.ac.uk/pabe/docs.htm.

Marsh, D., Rhodes, R., 1992. Policy networks in British government. Oxford University Press, Oxford.

Merrifield, J., 2002. A general equilibrium analysis of the insurance bonding approach to pollution threats. Ecological Economics 40, 103–115.

Millstone, E., 2007. Can food safety policy-making be both scientifically and democratically legitimated? Is so, how? Journal of Agricultural and Environmental Ethics 20, 483–528.

Mostert, E., 2008. Managing water resources infrastructure in the face of different values. Physics and Chemistry of the Earth 33, 22–27.

Mulkay, M., 1979. Science and the Sociology of Knowledge. Unwin Hyman, London.

Nap, J.P., Metz, P.L.J., Escaler, M., Conner, A.J., 2003. The release of genetically modified crops into the environment – Part I. Overview of current status and regulations. Plant Journal 33 (1), 1–18.

Newberg, J.A., Dunn, R.L., 2002. Keeping secrets in the campus lab: law, values and rules of engagement for industry-university R&D partnerships. American Business Law Journal 39 (2), 187–240.

Newell, P., 2003. Globalization and the governance of biotechnology. Global Environmental Politics 3 (2), 56–71.

Nielsen, K.M., 2006. Biosafety data as confidential business information. Unpublished paper.

O'Connor, M., van den Hove, S., 2001. Prospects for public participation on nuclear risks and policy options: innovations in governance practices for sustainable development in the European Union. Journal of Hazardous Materials 86, 77–99.

O'Neill, J., 1998. The Market. Ethics, Knowledge and Politics. Routledge, London.

Pistorius, R., van Wijk, J., 1999. The Exploitation of Plant Genetic Information: Political Strategies in Crop Development. CABI Publishing, Wallingford.

Podolny, J.M., Page, K., 1998. Network forms of organization. Annual Review of Sociology 24, 57–76.

Powell, W., 1990. Neither market nor hierarchy: network forms of organization. Research in Organizational Behavior 12, 295–336.

Ring, P.S., Van de Ven, A.H., 1992. Structuring cooperative relationships between organizations. Strategic Management Journal 13, 483–498.

Schoemaker, P.J.H., Schoemaker, J.A., 1995. Estimating environmental liability: quantifying the unknown. California Management Review 37 (3), 29–61.

Scientific American Magazine, 2009. Do Seed Companies Control GM Crop Research? August 2009. Available at http://www.scientificamerican.com/article.cfm?id=do-seed-companies-control-gm-crop-research.

Shorett, P., Rabinow, P., Billings, P.R., 2003. The changing norms of the life sciences. Nature Biotechnology 21 (2), 123–126.

Spash, C.L., 2002. Greenhouse Economics. Values and Ethics. Routledge, London.

Stirling, A., 1998. Risk at a turning point? Journal of Risk Research 1 (2), 97–109.

Stirling, A., Leach, M., Mehta, L., Scoones, I., Smith, A., Stagl, S., Thompson, J., 2007. Empowering Designs: towards more progressive appraisal of sustainability. STEPS Working Paper 3. STEPS Centre, Brighton.

Stone, G.D., 2002. Both sides now. Fallacies in the genetic-modification wars, implications for developing countries, and anthropological perspectives. Current Anthropology 43 (4), 611–630.

Sunstein, C.R., 2008. Two conceptions of irreversible environmental harm. University of Chicago, Law & Economics, Olin Working Paper No. 407; University of Chicago, Public Law and Legal Theory, Working Paper No. 218; Reg-Markets Center, Working Paper No. 08-16. http://ssrn.com/abstract=1133164.

Toman, M.A., 1994. Economics and "Sustainability": balancing tradeoffs and imperatives. Land Economics 70 (4), 399–413.

Ulph, A., Valentini, L., 2004. Environmental Liability and the Capital Structure of Firms. Resource and Energy Economics 26, 393–410.

Vatn, A., 2005. Institutions and the Environment. Edward Elgar, Cheltenham.

Webler, T., 1995. "Right" discourse in citizen participation: an evaluative yardstick, in: Renn, O., Webler, T., Wiedemann, P. (Eds.), Fairness and Competence in Citizen's Participation. Technology, Risk and Society nr 10. Kluwer Academic Publishers, London, pp. 35–86.

Weingart, P., 2004. Norms in Science. International Encyclopedia of the Social & Behavioral Sciences, 10720–10723.

Wilenius, M., 2005. Towards the age of corporate responsibility? Emerging challenges for the business world. Futures 37, 133–150.

Williamson, O.E., 1985. The Economic Institutions of Capitalism. Free Press, New York.

Williamson, O.E., 1991. Comparative economic organization: the analysis of discrete structural alternatives. Administrative Science Quarterly 36, 269–296.

Williamson, O.E., 1999. Public and private bureaucracies: a transaction cost economics perspective. The Journal of Law, Economics, & Organization 15 (1), 306–342.

Winter, G., Jans, J.H., Macrory, R., Krämer, L., 2008. Weighing up the EC Environmental Liability Directive. Journal of Environmental Law 20 (2), 163–191.

Wolf, C., 1979. A theory of nonmarket failure: framework for implementation analysis. The Journal of Law and Economics 22, 107–139.

Wolfenbarger, L.L., Phifer, P.R., 2000. The ecological risks and benefits of genetically engineered plants. Science 290, 2088–2092.

Wynne, B., 1992. Uncertainty and environmental learning: reconceiving science and policy in the preventive paradigm. Global Environmental Change 2, 111–127.

Zandvoort, H., 2005. Globalisation, environmental harm, and progress: the role of consensus and liability. Water Science & Technology 52 (6), 43–50.

Ziman, J., 1984. An Introduction to Science Studies. The Philosophical and Social Aspects of Science and Technology. Cambridge University Press, Cambridge.

Zweifel, P., Tyran, J.R., 1994. Environmental impairment liability as an instrument of environmental policy. Ecological Economics 11, 43–56.

# Valborg Kvakkestad

Department of Economics and
Resource Management
Norwegian University of
Life Sciences
PO Box 5003
N-1432 Ås,
Norway

Telephone: +47 6496 5700
Telefax: +47 6496 5701
e-mail*: ior@umb.no*
*http:/www.umb.no/ior*

**ISSN: 1503-1667**
**ISBN: 978-82-575-0893-7**

Valborg Kvakkestad was born in Askim, Norway, in 1976. See holds a cand. agric. degree in Economics and Resource Management from the Norwegian University of Life Sciences (2001). She was employed at this university from 2001 till February 2010. Currently she is employed at the Norwegian Agricultural Economics Research Institute.

The purpose of the thesis has been to analyse how different institutions can enable us to avoid harmful and generate beneficial environmental and food security effects of genetically modified organisms (GMOs)

Paper 1 analyses scientists' perspectives on GMOs, and the relationship between their perspectives and their background. Two main perspectives were identified. Perspective 1 emphasise the uncertainty and ignorance involved. Perspective 2 emphasise that GMOs are useful and do not represent any unique risks. The results show a strong association between scientists' perspective on GMOs and discipline, funding and place of employment.

By analysing 1323 field trials with GMOs in the EU paper 2 examines how different institutional structures shape the research and development (R&D) of GMOs. The results show that whether the R&D is conducted within companies, cooperatives or public research organisations influences strongly the type of GMOs that are developed.

Paper 3 analyses the regulation of the marketing of GMOs in the EU and Norway. They have assessed notifications for the release of GMOs as commercial products quite differently. When a decision is made, Norway has dominantly rejected the notification by emphasising no real benefit to society, lack of scientific knowledge, and involved risks. When a decision is made, the EU has approved the notifications by emphasising that there is no reason to believe that there will be any adverse effects on health and the environment.

Paper 4 emphasis that the nature of uncertainty implies that regulations for handling of uncertain effects of GM-crops will be incomplete. This incompleteness imply that it will be difficult to develop regulations that ensures that firms undertake the assessments of uncertainty, the marketing decisions and the monitoring of uncertainty in accordance with the will of the government. It might therefore be preferable that the state becomes responsible for these tasks.

Professor Arild Vatn was supervisor for this PhD thesis.

E-mail:valborg.kvakkestad@nilf.no