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"The worth of a wildflower"
Precautionary perspectives on the environmental risk of GMOs

Abstract:
How much is a wildflower worth? Inspired by "The worth of a songbird" by Funtowicz and Ravetz (1994) we use the value of a wildflower as symbol of the complexity of evaluating environmental qualities and risks. We critically discuss the application of cost-benefit analysis in evaluating environmental impacts of adoption of genetically modified organisms (GMOs). We argue that cost-benefit analysis should be supplemented with other methods, such as processes for assessing uncertainty, accommodation of scientific disagreements, and integration of stakeholders' interests and perspectives. A more inclusive perspective is to develop precautionary approaches that recognize the multidimensional nature of environmental qualities and risks, such as irreplaceability, irreversibility, uncertainty and complexity. Precautionary approaches can contribute to develop a stronger environmental responsibility within the framework of rational self-interest.

Keywords: cost-benefit analysis, environmental risk, environmental value, genetically modified organisms, precautionary principle, scientific uncertainty.

JEL classification: D81, Q20, Q50

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1. Introduction

How much is a wildflower worth? Inspired by "The worth of a songbird" by Silvio Funtowicz and Jerome Ravetz (1994) we use the value of a wildflower in its ecosystem as symbol of the complexity of assessing and managing environmental qualities and risks in the context of use and release of genetically modified organisms (GMO). The novelty of the genetic modification techniques and their applications, the long time horizon before health and environmental impacts can be assessed, the potentially irreversible effects on biodiversity, the widely divergent risk perceptions of different stakeholder groups, the various types of ethical concerns, and the enormous economic interests at stake for the biotechnology companies; these and numerous other factors contribute to the complexity of the risk governance, yet they indicate reasonable grounds for concern and provide the rationale for a precautionary approach. The challenge is to develop risk governance processes that recognize the intertwined scientific, political, economic and social context, strengthen environmental responsibility, and to design precautionary strategies that can prevent, or at least minimize, future harmful impacts while at the same time promoting innovation of sustainable GMOs.

Our aim in this paper is to develop a precautionary perspective on risk evaluation in the context of the environmental risk of GM crops. We draw upon "post-normal science", where focus on uncertainties in knowledge and complexities leads to a new perspective on science: When science no longer is imagined as delivering "truth" irrespective of context, science receives a new organizing principle, that of quality (Funtowicz and Ravetz 1994). Central to the principle of quality is a broader approach to environmental risk, moving from result-oriented rationality to procedural rationality, with focus on the process of knowledge generation instead of only on the final outcome. Procedural rationality implies an extension of the peer-review community to scientists from other disciplines and to people affected by the particular environmental issue. It recognizes the importance of context, ethical assumptions, and the possibility for democratisation of knowledge by an extension of the peer-community for accumulation of knowledge, encompassing the perspectives of multiple stakeholders.

From this perspective, cost-benefit analysis can be recognized as one approach among several, but not the whole story of environmental evaluation. Environmental policy makers should be made aware of the implicit assumptions in cost-benefit analysis about the value of nature and about human motivation, their divergence with real-world observations, and how assumptions define and influence the outcome of the analysis and the policy recommendations. Other methods should be considered, such as identification and systematisation of uncertainty, acknowledgement of complexity, and application of multicriteria methods and participatory processes (Walker et al. 2003, Beinat and

Nijkamp 1998, Munda et al. 1994, Janssen 1992). Dialogue between stakeholders can contribute to develop environmental responsibility on an individual level, in science, and in policy-making.

2. Environmental risk, quality and responsibility

With uncertain and complex environmental and health issues, there is a need to take into account the ethical responsibility of the scientists, as well as the social and environmental responsibility of individuals and enterprises. Jonas (1984) suggests that responsibility is a more basic ethical principle than reciprocity since there is no reciprocity between future generations and us. Environmental responsibility relates to human existence, and suggests that the Earth should not be left in a worse state than when the present generations received it. This perspective on environmental responsibility implies a precautionary approach, while at the same time encouraging innovation. Rather than a narrow interpretation of the precautionary principle with emphasis on "no harm", focus is shifted to the more conceptual issue of how we want to live with others and ourselves and nature.

This shift may have implications for how we approach uncertainty and complexity issues. For instance, modern science has not accepted the possibility of strong interaction between "seemingly unrelated" parts of the universe, and is reluctant to accept the existence of what cannot immediately be observed and quantified. Qualities that are not recognised and not taken responsibility for can reappear as monsters (Shelley 1818/1992, Douglas and Wildavsky 1982, Smits 2006).

While science often supposes that uncertainty is reduced by accumulation of knowledge, human passions continue to create uncertainty. The two pioneering works from 1921, Knight's "Risk, uncertainty, and profit" and Keynes' "A treatise on probability" illustrate the paradox that uncertainties created in human relations and social interactions are modelled in terms of probabilities. While Keynes recognized the unpredictability of human passions, Knight saw risk as something that could be calculated beforehand and turned into the cost, hence controllable. The sociologists Nowotny et al. (2001) argue that "this contemporary meaning of risk has to some extent eclipsed the more fundamental importance of uncertainty as an inherent feature". What is referred to as uncertainty can hide the distinction between uncertainty, risk, ignorance and ambiguity, hence, uncertainty is more than unknown probability or insufficient data (Dovers et al. 1996, Wynne, 1992).

In evaluating the risks of new technologies, Small and Jollands (2006) argue that it is essential to start from a deeper understanding of human nature. They suggest that there is a growing tension between the emerging technological power over nature and the current (in)ability of our human nature to deal with the potentially disastrous ecological and social consequences of technology diffusion. They use the metaphors of Prometheus and Pandora from Greek mythology to illustrate the power of technology and the risk that technology adoption will be guided by greed and narrow self-interest rather than by social and environmental responsibility.

We have the knowledge to manipulate nature, but do we have the wisdom to avoid unsustainable consequences? Small and Jollands (2006) suggest the distinction between three types of risk: accidental risk, incidental risk and malevolent risk. While accidental risks relate to unforeseen and unexpected events, caused by lack of knowledge, incidental risks arise when we become aware of the harmful consequences, without being able to or willing to deal with the problems immediately. In contrast, malevolent risk refers to the malevolent use of technology inflicting intentional harm to humans and the environment. A precautionary approach involves awareness of environmental problems as well a willingness to act on basis of the relevant information.

2.1 Quality and risk: Applications to GMOs

Despite large research efforts in GMO risk assessments, see e.g. EU (2001), unresolved issues remain in the assessments of long-term environmental and health risk. For instance: What aspects of the environmental risk from GMO release are suitable for cost-benefit analysis, and what aspects need a wider approach? What about distributional issues, contested benefits, and choice of discount rate? Some scientists express concerns about potentially irreversible impacts of releasing GM crops into the natural environment, while others emphasize 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, soil conservation and phytoremediation of polluted soil and surface water. The environmental risks related to GM crops involve the development of herbicide-resistant superweeds, non-target adverse effects on beneficial organisms, and loss of biological and genetic diversity (Andow and Zwahlen 2006, Myhr and Traavik 2003, Wolfenbarger and Phifer 2000).

Moreover, genetic modifications may enhance the ability of an organism to become an invasive species. While the majority of introduced plant species pose neither economic nor ecological problems, a few species become invasive and may cause serious damage to their new habitat, for instance in the US the estimated damage and control cost of invasive species amount to more than $138 billion annually (Pimentel et al. 2005). It is at present a lack of knowledge with regard to why certain species become such successful invaders, and there is little reliable predictive power about the nature and extent of future invasions. For instance, it is estimated that 80 per cent of endangered species could suffer losses due to competition with or predation by invasive species (Pimentel et al. 2005). An issue for risk management is how to identify those genetic modifications that may lead to or augment invasive characteristics (Warwick and Small 1999).

2.2. Risk issues: Spread of herbicide resistance

Benbrook (2005) examined some likely consequences for US farmers of Roundup Ready (RR) wheat adoption. If RR wheat is introduced, increased seed and herbicide costs and reduced wheat prices may outweigh the savings from simplified weed management. The Benbrook report concluded that RR wheat is a technology for which there is no compelling need. Existing weed management systems are stable, the price of weed management is not increasing, and farmers manage resistance to currently used herbicides. Another reason for caution is that a negative experience with RR wheat, for instance spread of herbicide resistance to the non-GM counterpart or wild relatives, could delay and jeopardize acceptance of biotechnology applications in the development of new wheat varieties, including applications that raise few food safety concerns, for example, wheat varieties that are resistant to *Fusarium* blight. Rejection of breeding tool with roots in biotechnology might impair adoption of new *Fusarium* resistant wheat varieties developed by conventional breeding techniques, augmented with biotechnology-based gene mapping and gene-marker tools (Benbrook 2005). To improve risk communication and recognize the social context, the Benbrook report suggests that farmers, scientists, and biotechnology industry cooperate in carrying out an in-depth and independent appraisal of the impacts of adoption of RR wheat before approval and commercial release.

2.3. Risk issues: Reduced genetic diversity

Adoption of GM crops may reduce the genetic diversity in important food crops. The corn species *Zea mays* is no longer found in the wild, but close relatives, known as teosinte (*Z. diploperennis, Z. perennis, Z. luxurians, and Z. nicaraguensis*) represent valuable gene reservoirs together with several local cultivated land races of *Zea mays*. These unique resources may be contaminated with pollen from GM maize. If GM maize crops are released, they might compete out the local land races with their unique genetic variation.

The controversy over the *Nature* article by Quist and Chapela (2001), who found transgenes in five out of seven native varieties of maize in Mexico, illustrates the importance of considering the scientific context that risk evaluation takes place within. As Sarewitz (2004) suggests with reference to this case, uncertainty about environmental impacts can be understood not only as lack of scientific knowledge, but also as lack of coherence between competing scientific disciplines, each with their traditions, approaches, and models. The value orientation and normative assumptions implicitly held in different scientific disciplines can represent contrasting scientific views of nature and human nature, and of the ethical responsibility of the scientist. Each scientific discipline hence represents a different frame for perception of environmental uncertainty, and the values and implicit normative assumptions need to be fully articulated in order to interpret to what extent a particular scientific disagreement represents “lack of knowledge” or “lack of coherence”.

> “Yet on another level that was never discussed, the disciplinary structure and disunity of science itself was at the roots of the controversy. The two sides of the debate represented two contrasting scientific views of nature—one concerned about complexity, interconnectedness, and lack of predictability, the other concerned with controlling the attributes of specific organisms for human benefit. In disciplinary terms, these competing views map onto two distinctive intellectual schools in life science—ecology and molecular genetics” (Sarewitz 2004, p. 391).

What Sarewitz here points to as an explanation of the controversy over the Quist and Chapela analysis of reduced genetic diversity, illustrates the importance of articulating those implicit values and assumptions that impair constructive dialogue between scientific disciplines. For example, the implicit assumptions of cost-benefit analysis do not address the distinction between nature as a source for individual consumer goods and nature as ecological processes, nor the distinction between human motivation from responsible self-interest or from addictive consumption behaviour. Different perspectives on human motivation, the role for individual responsibility, and the relationship between human activity and ecological processes provide different perspectives on environmental risk and the value of biological and genetic diversity. Furthermore, the different perspectives influence how the perception of environmental risk is constructed by implicit values, scientific disunity, and economic interests.

2.4. Risk issues: Economic and social aspects

The uncertainties of environmental and health impacts of GMOs are intertwined with economic and social uncertainties (Batie and Ervin 2001). Public concern about GM food relates to the potential environmental and health related risks involved (Burton et al. 2001, Noussair et al. 2002, Pryme 2003), as well as economic risks (Harhoff et al. 2001, Zilberman and Lipper 2005). Genetic modifications of crops have primarily been motivated from the production side, in order to increase agricultural output, rather than from a consumer demand and health perspective. Batie and Ervin (2001) refer to this as “technology-push” rather than “demand-pull”. Manufacturing of GM seeds takes place in an industrial structure characterized by strong integration of seed and herbicide production. At present in the US and worldwide 71 per cent of the GM crops grown commercially (James 2005), e.g. soybean, maize, oilseed rape and cotton, is herbicide-tolerant and is developed and promoted by chemical companies. Adoption of herbicide-tolerant GM crops and new market opportunities for herbicide may create incentives to promote GM crops too early, relative to socially optimal levels of risk assessment. If a technology is introduced to replace a previous technology causing environmental problems, new problems associated with the new technology may readily be overlooked (EEA 2001). In a cost-benefit analysis of GM crops in Europe, Wesseler (2003) has analysed the benefits of GM crop adoption in terms of reduced pesticide use and its positive impact on human health, as well as the effect on ground water quality and on bio-diversity, however, in this study potentially adverse long-term effects were not taken into account. A precautionary approach to food security would be to not only promote adoption of GM crops, but also to promote environmentally sound improvement in traditional agriculture, innovations in organic farming, and preservation of genetic diversity in agriculture.

The issue of patents and ownership rights over genetic resources being transferred to the private sector raises concern. The introduction of terminator genes has given rise to particular consideration. Farmers can no longer depend on own production of seeds, but have to buy seeds and may be threatened by litigation if their native crops unintentionally are polluted by airborne GM pollen (Warwick and Meziani 2002).

If early adoption of a new technology is highly profitable, and there is scientific controversy about long-term environmental and health effects, it is likely that public concern is relatively high. European survey data show that many people's concern are related to a wish for transparency in decision making about GM food, a questioning of the market power of the multinational companies, i.e. at present a few companies dominate the development and commercialization of GM crops, and a concern for implications for landscape and culture embedded in the agricultural system (Marris et al. 2001). The biotechnology industry has a role to play in developing environmental responsibility, by improving risk communication with various stakeholders, providing information for improved risk assessments, and acknowledging risk management as their contribution to social and environmental responsibility (Aslaksen et al. 2006). To improve information, it is necessary to get beyond the conflict of interest caused by the claim to confidential business information. Access to information and accumulation of knowledge via peer review is needed in order to build public understanding and confidence in GMOs in addition to directing further research activities in areas of uncertainty (Nielsen 2006). Increased focus on corporate social responsibility can strengthen the process of more transparency in risk communication, simply because withholding information can harm company reputation (Paine 2003).

2.5. Risk issues: How to apply the precautionary principle?

The large economic incentives for early adoption of GM crops may conflict with incentives for sufficient risk assessment, risk management and risk communication, suggesting that GMO use and release, without due consideration of precautionary approaches, can represent an example of a Promethean technology with Pandorean potential. The scientific and political processes surrounding GMOs do not address the Pandorean aspects of human decision-making. Precautionary approaches are called for.

With regard to GMO regulations, the precautionary approach plays an important role in the Cartagena Protocol on biosafety, and the precautionary principle also is employed in regulations such as the Norwegian Gene Technology Act of 1993 and the EU directive 2001/18/EC. However, at present there are discussions going on with regard to how the precautionary principle should be implemented and how precautionary approaches are to be facilitated. Several formulations of the principle, ranging from ecocentric to anthropocentric, and from risk-averse to risk-taking positions, have been put forward (see Boxes 1 and 2). A weak version of the precautionary principle is often grounded in purely utilitarian ethics, and its application involves risk/cost-benefit analyses (Myhr and Traavik, 2003). In this context, the precautionary principle may be used as an option to manage risks when they have been identified through risk analysis. For instance, the Rio Declaration employs the weighing of costs and benefits; cost-effective measures (see Box 1).

Box 1. Weak version of the precautionary principle

The Rio declaration: In order to protect the environment, the precautionary approach should be widely applied by States according to their capabilities. Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation (RioDEC, 1992).

Box 2. Strong version of the precautionary principle

The Bergen declaration: In order to achieve sustainable development, policies must be based on the Precautionary Principle, environmental measures must anticipate, prevent, and attack the causes of environmental degradation. Where there are threats of serious or irreversible damage, lack of full scientific certainty should not be used as a reason for postponing measures to prevent environmental degradation (Cameron and Abouchar, 1991)

Strong versions of the precautionary principle embrace inherent values of the environment and often are founded in ecocentric views or duty-based concerns for non-human beings and ecosystems (see Box 2). A strong version is active in nature and obliges regulators to take action, for instance by implementation of risk management procedures. The difference between the weak and strong version lies mainly in the demand for scientific evidence and in the ethical significance of scientific uncertainty. The Bergen declaration is an example of a strong version of the precautionary principle. Most interestingly, the recent UNESCO report on the precautionary principle (UNESCO 2005) takes a different approach by emphasising a precautionary approach to novel and complex problems although uncertainty may not be obvious at the time risk management decisions need to be made.

These different definitions and approaches to precaution form the basis for our discussion of precaution and valuation. From this perspective, the weak versions of the precautionary principle may be considered extended cost-benefit analyses. Cost-benefit analyses can be recognized as one approach to evaluating environmental risk, but may be too limited when taking into account the extent of uncertainty and complexity problems, due to the implicit assumptions about values and preferences in cost-benefit analysis.

3. Cost-benefit analysis, preferences, and rationality

Cost-benefit analysis is widely used as a tool for valuation of nature and for providing policy advice on management of natural resources and the environment. Recently, many authors have questioned the assumptions of environmental valuation studies and their applications in cost-benefit analysis (Vatn and Bromley 1994, Vatn 2005, O'Neill 1993, O'Neill and Spash 2000). A main critique of cost-benefit analysis is that the value of nature is incommensurable with other values, and that nature represents irreplaceable qualities that are beyond economic comparison with ordinary, produced goods. Nature has irreducible complexity that defies one-dimensional valuation and entails a plurality of legitimate perspectives and values, and multi-dimensional measures of value are needed to reflect the commitments of different stakeholders (O'Neill 1993). In cost-benefit analysis harm to nature is seen as a cost that in principle can be recompensated. However, cash payment may not necessarily recompensate for the loss of a context that provided meaning to life (O'Neill 1996). "If the valued goods that give richness to our lives are reduced to commodities, then what makes those lives meaningful is itself betrayed" (Funtowicz and Ravetz 1994, p. 197). Environmental and cultural qualities are intertwined (Jamieson 1992). To pay can be to bribe (Goodin 1994). The challenge for environmental risk management is to include the value of a wildflower, with its qualities that are not easily expressed in terms of market value. The failure of market prices to reflect potential health and environmental risk can give GM crops an unjustifiable advantage in the market place.

Cost-benefit analysis without qualitative values can appear as an abstraction without context, being "blind" to natural and cultural values that are difficult to measure, considering nature values as similar to the value of other goods, without taking into account the ecological processes and the social and cultural context that these nature values are embedded within. This apparent "blindness" may induce a criticism that questions the relevance of economic trade-off for valuation of environmental qualities altogether. Pearce (1998) argued that it is more appropriate not to criticize economic valuation per se, but, when needed, to place a higher value on nature. As we suggest in Figure 1, a bridge across the duality between abstract monetary valuation and rejection of economic trade-off is to develop complementarity between monetary and non-monetary valuation, emphasizing that multidimensional evaluation of environmental qualities, uncertainties, and impacts should take place in deliberative processes that recognize the social context of risk evaluation.

Figure 1. Valuation and evaluation in social context

Economic valuation	and	Evaluation in context
Abstraction without context		Rejecting economic trade-off

Who represents nature as stakeholder? Harm to nature that reduces its qualities affects many types of stakeholders. In a sense, we are all stakeholders. While Nyborg (2000) expands the notion of "Economic man" to include citizens' preferences, O'Neill and Spash (2000) indicate that preferences shift when individuals are encouraged to express values they have as public citizens rather than private consumers. Individual valuation may change in the valuation process, as more information becomes available to respondents, see Hanley et al. (1995). In a study of biodiversity, they found some indication of lexicality in preferences, that is, some values are given priority before the trade-off between other values are considered, implying that there is not a complete trade-off between the value of biodiversity and other goods. As a parallel to the metaphor of "Economic man", Soma (2006) has developed the metaphor of "Natura economica", to describe the value of nature and the environment as implicitly understood in cost-benefit analysis, namely as a bundle of commodities with a potential market value, and she suggests ways to expand the models of "Economic man" and "Natura economica" to take into account the environmental, social and political context of the management of environmental uncertainty.

The notion of rationality implicit in cost-benefit analysis assumes the model of "Economic man", where economic actors are motivated by rational self-interest and in some sense have unlimited wants, "more is better". The theory of "Economic man" generally does not address the distinction between motivation by "more is better" to a reasonable degree, in a context of personal, social, and environmental responsibility, and motivation by greed. Pearce (1998) emphasized that economics has a wider ethical foundation that what is usually conveyed via that image of "Economic man" and that environmental responsibility is not incompatible with individual rationality. However, as he points out, the discussion of the ethical basis and the importance of context are often not carried through in applied economics. Environmental impacts of economic activity are denoted "externalities", by definition, external to the responsibility of the individual decision-maker. Internalizing externalities is perceived as an issue for public policy only, designing effective policy means, rather than an issue of developing individual responsibility.

One might argue that the unqualified assumption of "more is better", regardless of social and economic context, to some extent reflects an inherent greed in human nature, a lack of individual responsibility. Seeds of greed grow in the soil of indifference. In an essay on economics, the psychologist David Winnicott reflects on the somewhat puzzling lack of explicit discussion of greed in economic theory: "… economics has often seemed like a science of Greed in which all mention of Greed is banned" (Winnicott 1945, p. 170). Focusing on greed as an aspect of economic motivation can make us more aware of how behaviour in accordance with the standard economic assumption that "more is better" may contribute to addictive and excessive consumption and, hence, excessive environmental impact and environmental devastation (Nicholsen 2002). The focus on individual self-interest in economic theory of valuation to some extent reflects a concern for loss of freedom of choice (Pearce 1998). However, by highlighting only the positive qualities of individual agency, its unconscious side, with greed and lack of concern for others, becomes invisible and unaccounted for and less accessible for personal responsibility (Klein 1956, Wachtel 2003, Whybrow 2005). By recognizing the conscious as well as the unconscious forces of human motivation, we as individuals become aware of our capacity to develop a positive complementarity between rational self-interest and social and environmental responsibility, as we suggest in Figure 2.

Figure 2. Developing environmental responsibility

Rational self-interest	and	Environmental responsibility
Unconscious greed		Loss of freedom of choice

The challenge for economics is to more explicitly recognize how “my actions influence your possibilities” (Vatn 2005), recognizing that individual well-being includes developing preferences and capacities that enable us to make well-informed and well-reflected actions, and not simply satisfying whatever desire one has (O’Neill 1993). As expressed by Robert Pirsig in his search for quality: “The social values are right only if the individual values are right. The place to improve the world is first in one’s own heart and head and hands, and then work outward from there” (Pirsig 1974, p. 297).
In developing the notion of environmental responsibility, Jonas (1984) discusses the “necessity of metaphysics” as foundation for ethics, considering “that anthropocentric exclusiveness could be a prejudice and that it at least calls for re-examination” (Jonas 1984, p. 46) and suggests that the tacit metaphysics imbedded in each discipline should be made explicit. In an essay on the nature perspectives of Malthus and Wordsworth, Becker et al. (2005) see nature as a reference point for the human mind in its creative capacity, providing orientation in life. The wildflower’s worth, like the songbird's, also lies in its teaching us about ourselves and what we want to do with our lives while we are here (Funtowicz and Ravetz 1994, p. 206).

4. Fitness of purpose; How to apply the precautionary principle?

Political approaches to environmental risk, in particular at local and regional level, almost exclusively focus on technical solutions, neglecting the questions: What type of nature and biodiversity conservation do we want to achieve? What is the authentic quality in this particular type of nature? Which results of historic development in nature should be preserved, which apple gardens, mountain pastures and heather moors? Who are the stakeholders representing the wildflower? What is it like to be human without this place (Latour 2004)? Raising these questions has implications for how to employ risk governance, and represents a different dimension than optimism or pessimism, different than being “for or against” GMOs, by demanding perspectives at a more conceptual level about the needs, goals and stakes for a given application. Considering the purpose of a GMO application from the perspective of society and taking into account the potential harm to a wide range of stakeholders implies a much wider context than what the employment of cost-benefit analysis encompasses. Furthermore, the present uncertainty and the complexity of the ecosystems make it difficult to apply cost-benefit analyses, hence, a weak version of the precautionary principle may not work according to its intention. This ultimately raises the question: How to apply the precautionary principle in risk management decisions on GMOs?

4.1. Fitness of purpose; implications for science

Nature itself is sufficiently rich and complex to support a wide range of hypotheses framed by a diversity of methodological, disciplinary, and institutional approaches (Sarewitz 2004). What Sarewitz denotes "excess of objectivity" refers to the observation that available scientific knowledge can legitimately be interpreted in different ways to yield competing views of a problem and of how society should respond. Different scientific disciplines employ competing models and basic assumptions, for instance, molecular biologists refer to the controlled laboratory practice, plant biologists refer to the history of conventional plant breeding, while ecologists argue that the experiences based on the introduction of novel species into new environments need to be the basis for risk assessment of GMOs. Hence, not only lack of scientific understanding but also lack of coherence contributes to uncertainty about GMOs. What is needed is an explicit discussion of the plural values and scientific approaches involved in a particular environmental controversy.

Employment of model-based decision support, as for instance the Walker & Harremöes et al. (2003) (W&H) framework, may help to identify the types and levels of the uncertainty involved in environmental decision-making, in order to stimulate communication between the actors in the decision processes. Krayer von Krauss et al. (2004) have demonstrated and tested the W&H framework with the purpose to identify scientists' and other stakeholders' judgement of uncertainty in risk assessment of GM crops. In these studies the focus was on potentially adverse effects on agriculture and cultivation processes by release of herbicide resistant oilseed crops. Krayer von Krauss et al. interviewed seven experts in Canada and Denmark. To identify the experts' view on location uncertainty (where the uncertainty is manifested), the authors presented a diagram showing causal relationships and key parameters to the experts. With the purpose to identify the level of uncertainty (ranging from "knowing for certain" to "complete ignorance") and nature of uncertainty (whether uncertainty stems from inherent system variability and complexity or from lack of knowledge), the experts had to quantify the level and describe the nature of uncertainty on the key parameters in the diagram. By asking the experts to identify the nature of uncertainty it was possible to distinguish between uncertainty that may be reduced through more research and uncertainty and ignorance that stem from systems variability or complexity.

Reflecting on the role of scientific disunity in the interpretation of environmental uncertainty, as suggested by Sarewitz (2004), the question arises how enhanced dialogue between competing disciplines can contribute to make explicit those values, interests, and implicit assumptions that represent the frame for each discipline's approach to scientific uncertainty and quality in nature. For example, Norgaard (2002) suggests that the history of industrial economies, as one of overcoming scarcity through innovation, has conditioned economic thinking into conventionally assuming that all scarcity, including scarcity of environmental assets, will be overcome in a similar manner. Focusing on the promise of Promethean technologies while neglecting the Pandorean potentials, technological optimism may overlook its shadow side of "blind optimism". The viewpoint of "blind optimism" tends to see "blind pessimism" as its only alternative. Focusing on participatory processes and risk communication suggests a way for overcoming the duality between "blind optimism" and "blind pessimism" and for developing precautionary approaches, as we suggest in Figure 3, with complementarity between sound optimism and precaution.

Figure 3. Technological optimism and precaution

Technological optimism	and	Precautionary approaches
Blind optimism		Blind pessimism

4.2 Fitness of purpose; the need for extended peer-review

Institutional economists suggest a role for the "forum" in providing information and enhancing dialogue between stakeholders (O'Neill 1996, Vatn 2005). In the context of GMO related risk, the participants of the "forum" would be scientific experts, biotechnology industry, consumers, regulating authorities, and other stakeholders, each contributing with their unique perspective: Scientific experts can provide the best available risk assessment and state the need for more information, industry can develop a dialogue with other stakeholders and find ways to enhance social and environmental responsibility while ensuring long-term profitability, lay people can express their concern for quality and safety, and regulating authorities can develop a dialogue on incentive effects. Lay people may help to address the implications of uncertainty and complexity, for instance asking questions about aims, purposes, controlling interests and conditions (Wynne, 2001). This process may also enrich the process of scientific investigations by providing knowledge of local conditions and resources. For instance, what should be used as a normative standard for evaluation of harm – is no greater environmental harm than caused by conventional agriculture an acceptable standard for risk assessment of GM crops? Sustainable development of agriculture involves preservation of local knowledge and culture along with environmental improvements – can GM crops contribute to this? Are GM crops the solution or should genomics be used to help breeding, with the purpose to enhance productivity in agriculture?

Central to the principle of quality in risk management is the recognition that the scientific, economic and social contexts are intertwined, and new institutions for participatory processes are needed to strengthen dialogue between stakeholders, with respect to selection of hypotheses, formulation of burden of proof, and evaluation of evidence. Evaluation methods could include multicriteria analysis and deliberative processes for assessing uncertainty, for accommodation of scientific disagreements, and for integration of stakeholder perspectives. Risk perception varies between stakeholder groups, and risk may be seen as having an element of social construction (Slovic 2001). Jensen et al. (2003) apply the concept "risk window" to illustrate that risk assessments view the world through a "risk window" that only makes visible that which has been predefined as a relevant risk. The size and structure of this window is determined by value judgements about what is considered relevant as adverse effects identified in the process by the involved stakeholders. Hence, it must be expected that stakeholders use different conceptual frameworks, defined as a set of basic beliefs, values, attitudes and assumptions creating a frame through which they see themselves and the world, in their identification of which values are important to protect. An integrated assessment approach involves the handling of technical facts and social issue that almost always are incommensurable since it is difficult to construct precise distinctions between empirical facts and value judgements (Giampietro et al. 2006). In both the strong and the weak versions of the precautionary principle the focus is on scientific uncertainty, hence there must be some scientific indication or evidence for the probable harm that needs to be avoided. The recent UNESCO report on the precautionary principle (UNESCO 2005) replaces scientific probability with plausibility: "*When human activities may lead to morally unacceptable harm that is scientifically plausible but uncertain, actions shall be taken to avoid or diminish that harm",* hence uncertainty is not reduced to probability since it opens up for employment of precautionary approaches on the basis of identified plausible harms. However, this version involves another problem: How to identify "morally unacceptable harm", which ultimately raises the question of what type of harm, for whom, for how long time, and at what cost? The only way to get an answer is to involve the stakeholders.

Multi-criteria methods has been suggested as a useful analytical tool for mapping divergent social preferences, and has been developed as software based technique for exploring the links between scientific/expert analysis and divergent social values and interest. For instance, Mayer and Stirling (2002) have used multi-criteria mapping in a pilot study of GM crops in the UK, and they identified several elements of a precautionary approach, such as diverse approaches, acknowledgment of the many sources of uncertainty, transparency of risk assessment methods, systematic consideration of claimed benefits and risk on a comparative basis, and participation of all affected parties. Multicriteria methods provide a powerful framework for policy analysis since this type of evaluation processes accomplishes the goals of being interdisciplinary (with respect to research team), participatory (with respect to stakeholders) and transparent (since all criteria are presented in their original form without any transformations into money or other measurement rods).

5. Concluding remarks

In order to develop a precautionary perspective on environmental risk, the multidimensional nature of the environmental processes needs to be explicit, as well as the social and political context for understanding scientific uncertainty. Cost-benefit analysis is one element in a process that aims at making explicit the consequences of environmental risks for the natural qualities that should be preserved. The empirical relevance of our critique of traditional use of cost-benefit analysis is that we outline an expanded framework for evaluating environmental values and risks. We suggest that GMO developers as well as scientists take a more active role in developing fora for risk communication, extended peer-review and dialogue between stakeholders. This may contribute to improving the empirical basis for policy advice on how to deal with environmental risk and protect environmental qualities. To conclude, rather than aiming at a particular definition of a precautionary principle, we suggest that a precautionary approach should include the following elements:

1. Recognize the social dimension of the risk concepts (hazard, risk, uncertainty, ignorance and ambiguity), as in the distinction between different types of risk according to lack of knowledge, awareness of consequences, and intentional harm.
2. Consider potential long-term adverse consequences for health and the environment. Take into account contested benefits.
3. A more profound approach to human nature, questioning the notion of market-based preferences as the sole guideline for environmental responsibility, and understanding the social and psychological dimension of risk.
4. Consider the implicit ethical assumptions in different scientific approaches. The ethical responsibility of the scientist.
5. Accommodation of scientific disagreement and developing a more humble attitude towards technological improvements. Transparency in risk assessment processes.
6. Learn from past experiences to detect “early warnings”.
7. A participatory approach is needed, to enhance dialogue between all stakeholders, applying multicriteria analysis, and developing the incentives for corporate social responsibility.

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