Precautionary Principles: General Definitions and Specific Applications to Genetically Modified Organisms

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Abstract

Precautionary principles have been proposed as a fundamental element of sound risk management. Their advocates see them as guiding action in the face of uncertainty, encouraging the adoption of measures that reduce serious risks to health, safety, and the environment. Their opponents may reject the very idea of precautionary principles, find specific principles unacceptably vague or see them as clearly doing economic damage—either to society as a whole or to their own interests. This article traces the development of alternative precautionary principles, primarily in Europe. Their adequacy is considered in one context where such principles have often been invoked, using genetically modified organisms (GMOs) in agriculture. Although some precautionary principles can be given analytical rigor, the concerns that they express strain the intellectual and institutional structure of conventional policy analysis. © 2002 by the Association for Policy Analysis and Management.

> In order to protect the environment, the precautionary principle approach shall 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. (United Nations, 1992; article 15)

> Accepting that, in order to protect the North Sea from possibly damaging effects of the most dangerous substances, a precautionary approach is necessary which may require action to control inputs of such substances even before a causal link has been established by absolutely clear scientific evidence. (Second International Conference on the Protection of the North Sea, 1987, p. 7)

BACKGROUND

Precautionary principles have emerged as a fundamental challenge to conventional policy analysis, for risk-related activities surrounded by great uncertainty. For some proponents, these principles provide a decision-making rule that should be incorporated in conventional policy analyses; for others, the principles pick up where analysis fails (Santillo et al., 1998; Santillo, Johnston, and Stringer, 1999). For some critics, these principles embody a flawed decision-making rule, disproportionately valuing some risk-related consequences over other concerns. For other critics, precautionary principles threaten reasoned analysis itself (Gray, 1990; Gray and Brewers, 1996; Gray et al., 1991; Wildavsky, 1988).

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To some extent, these disagreements reflect different values, regarding either the choices that societies should be making or the processes for making them. The process issues concern the appropriate roles for the state, industry, independent scientists, citizens, and technical policy analysts in regulatory affairs (e.g., Boehmer-Christiansen, 1994; Leiss & Chociolko, 1994; Tait, 2001). To some extent, though, these disagreements reflect the lack of a consensual precautionary principle, complicating communication—even within the camps of critics and defenders. One compilation (Sandin, 1999) lists 19 formulations, often individually vague and mutually contradictory. Two prominent ones open this article.

Here, two converging approaches are adopted to clarify what precautionary principles do and could mean. One tracks the evolution of precautionary principles as they have arisen in specific, particularly European, regulatory contexts. The second considers the concerns that motivate the invocation of such principles, focusing on one widely mooted risk: genetically modified organisms (GMOs) in agriculture and food.

Contemporary History of Precautionary Principles

Sweden

In European regulatory contexts, the first legal use of the concept (although not the explicit term) arose in the 1969 Swedish Environmental Protection Act (Löfstedt, 2001; Sand, 2000). It reversed the conventional burden of proof, requiring industry to demonstrate the safety of environmentally hazardous activities (Swedish Government, 1969; Westerlund, 1975). Moreover, "the authorities do not have to demonstrate that a certain impact will occur; instead, the mere risk (if not too remote) is to be deemed enough to warrant protective measures or a ban on the activity" (Westerlund, 1981, p. 231). Applications of the Swedish approach typically involve a stringent needs analysis, requiring industry to demonstrate that a new product's public benefits outweigh its public health and environmental costs, relative to existing ways of addressing that need. Thus, in principle, it means that any risk that is not truly remote could stop a program—absent social consensus to consider compensating benefits.

West Germany

At about the same time, the German government began to develop a less demanding version of the precautionary principle, *Vorsorgungsprinzip*, or "cautionary principle," which took shape over several years. Its literal meaning is "showing prior care or worry"; in a 1988 review of its usage in German air pollution legislation, Konrad von Moltke saw the common thread as "precaution and foresight, implying good husbandry" (Boehmer-Christiansen, 1994, p. 38). It initially emerged from the Social Democrat–Liberal Democrat election victory in 1969, won partially on a platform promoting both environmental protection and a fairer society. This version of the principle attempted to address both issues, by moving away from purely economic policymaking criteria (Wey, 1993). *Vorsorge* was first applied to environmental issues in 1970, when the initial draft of the new Clean Air Act endorsed *"dem Enstehen schadlicher Umwelteinwirkungen vorzubeugen"* ("preventing the development of harmful effects" [Wey, 1993, p. 207]). The prime mover for this principle[1] was the

[1] The German term *vorzubeugen* was taken from medicine, as was the equivalent *förrebygga* in Swedish.

Liberal Democrat Hans Dietrich Genscher, who had environmental affairs moved from the Department of Health to his more powerful Ministry of Interior (BMI) (Weidner, 1991, p. 14). The Clean Air Act (passed in 1974) aimed at reducing emissions, using *Vorsorge* as its primary policy principle. The federal government invoked it when forcing industries to install pollution-abatement equipment, as a condition for re-licensing. It also called for a 90 percent reduction in all pollution from mobile sources by 1980, a goal finally achieved in 1990 (Boehmer-Christiansen, 1994).

German use of *Vorsorge* involved constant clashes with both industry and the powerful Ministry of Economics. In response, BMI enlisted public support, drawing on widespread concern over air pollution and its contribution to *Waldsterben* (forest death caused by acid rain). BMI presented environmental cleanup as a form of Green Keynesianism, coupling environmental protection with economic growth and technical progress. Pointing to the 1972 Stockholm Conference on the Environment, BMI advocated making West Germany a leader in international environmental negotiations, as part of its post-War rehabilitation. Whereas the Swedish experience primarily addressed domestic concerns, the German precautionary principle increasingly defined its place in the international arena, both economically and politically, and laid the groundwork for current international controversies.

Over time, German industry, as well as the politically conservative Christian Socialist Union (CSU) and Christian Democratic Union (CDU), became more receptive to a precautionary principle. Both had their power base in the prosperous southern regions of Bavaria and Baden-Wurttemberg. These regions had both most of the country's forest cover and most of its car manufacturing and nuclear power plants. The link between *Waldsterben* and auto emissions created a conflict between the environment and economic growth. Applying pressure on fossil fuel power plants, mostly located outside the region, reduced pressure to lower auto emissions, while promoting locally controlled nuclear power plants.

Ironically, this invocation of a precautionary principle endorsed a technology (nuclear power) that was itself surrounded by great uncertainty—although it was not as controversial then as it would later become. The policy was framed as representing "ecological modernization," in which environmental protection and economic development are mutually reinforcing (Hajer, 1995; Weale, O'Riordan, and Kramme, 1991). The policymakers also hoped to stimulate industrial research and open export markets for German environmental technology. Although conservatives returned to power in 1983, the government continued to use this precautionary principle to justify ambitious environmental targets, with industry seeing it as promoting international competitiveness. This "eco-industrial" sector was credited with creating 320,000 German jobs by 1992 (OECD, 1992). The German experience is an early example of a precautionary principle being used, in part, to promote economic and political concerns, unrelated to the environment.[2]

[2] A 1984 report (Boehmer-Christiansen, 1994, p. 53) to the Federal Parliament on the Protection of Air Quality from the Federal Interior Ministry argued:

> "The principle of precaution commands that the damages done to the natural world should be avoided in advance and in accordance with opportunity and possibility. *Vorsorge* further means the early detection of dangers to health and environment by comprehensive, synchronised (harmonised) research, in particular about cause and effect relationships..., it also means acting when conclusively ascertained understanding by science is not yet available. Precaution means to develop, in all sectors of the economy, technological processes that significantly reduce environmental burdens, especially those brought by the introduction of harmful substances."

Europe

Precautionary principles were discussed internationally as early as the 1982 World Charter for Nature (Sand, 2000). Early discussions focused on fish stocks and pollution in the North Sea, and other marine environment issues (Fairbrother and Bennett, 1999; Hey, 1991; McIntyre and Mosedale, 1997). *Marine Pollution Bulletin* has hosted a long-running debate over the scientific merit of competing precautionary principles (e.g., Gray, 1990; Santillo et al., 1998). These principles represent a shift away from the policy paradigm of "assimilative capacity"—assuming that the seas can absorb very large quantities of waste (or extractive exploitation) without unacceptable consequences. Jackson and Taylor (1992) argue that this paradigm failed for several reasons, each encouraging a more precautionary approach:

- Crude assumptions about the seas' ability to sequester, dilute, and disperse wastes,
- Inadequate policy responses to recognized environmental degradation, and
- Increased evidence of causal links between specific emissions and specific effects.

Over time, precautionary principles emerged in other environmental areas, motivated by both economic and environmental concerns (Jordan and O'Riordan, 1999). Germany lobbied the European Union to adopt *Vorsorge* as its standard for environmental policy. However, European adoption was delayed by individual states' concerns over its costs and benefits (Weale, 1998). Nonetheless, the German version of the precautionary principle was gradually incorporated in European environmental legislation (Jordan, 1998; Vogel, 1995), including the 1992 Fifth Environmental Action Program and the 1992 Maastricht Treaty, under Article 174 (Jordan and O'Riordan, 1999). This acceptance explicitly acknowledged the economic argument that "Anticipatory standardization (is) essential for the development of new technologies [that] have infrastructure characteristics, so that companies will not invest against each other until one or more backs down" (Narjes, 1988, cited in Boehmer-Christiansen, 1994, p. 50). That is, the value of precautionary principles could be realized only if a single version were adopted. Germany's ability to make that its version seems to have reflected both its power in the EU and its advocacy of a less risk-averse principle than the Swedish one.

International Arena

Once adopted by these European bodies, precautionary principles spread quickly, including Principle 15 of the UNCED Rio meeting (cited above) and the Cartagena Biosafety Protocol (discussed below). Sand (2000) cites its role in 14 multilateral agreements (Table 1).

Precautionary Principles Today

Erosion of Trust

The increasing acceptance of precautionary principles has, however, been accompanied by changes in their public profile. Many European industries decreasingly view precautionary principles as acceptable risk management approaches and increasingly view them as tools for environment and health advocates. These industries' disenchantment is fed both by decreasing control over regulatory bodies' interpretation of "precaution" and by seeing precautionary principles endorsed by

Table 1. Multilateral agreements citing precautionary principles.

- 1991 Bamako Convention on the Ban of Import into Africa and the Control of Transboundary Movement and Management of Hazardous Wastes within Africa
- 1992 UN Framework Convention on Climate Change
- 1992 UN/ECE Convention on the Protection and Use of Transboundary Watercourses and International Lakes
- 1992 Paris Convention for the Protection of the Marine Environment of the North-East Atlantic
- 1992 Convention on Biological Diversity, Preamble
- 1992 Helsinki Convention for the Protection of the Baltic Sea Area
- 1994 Oslo Protocol on sulfur emission reductions
- 1995 Straddling Fish Stocks Agreement, implementing the UN Convention on the Law of the Sea
- 1996 Syracuse Amendment Protocol (to the 1976 Barcelona Convention) for the Protection of the Mediterranean Sea against Pollution from Land-Based Sources, Preamble
- 1996 London Amendment Protocol to the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter
- two 1998 Aarhus Protocols on heavy metals and on persistent organic pollutants
- 1999 Gothenburg Protocol on acidification, eutrophication and ground-level ozone to the 1979 UN/ECE Convention on Long-Range Transboundary Air Pollution, Preamble
- 1999 (UN/ECE) London Protocol on Water and Earth

Source: Sand (2000).

individuals with very different worldviews. These proponents advocate precaution as a response to globalization and the so-called "risk society"—where risks extend over time and national boundaries, without compensating many of those affected by them (Beck, 1992; Giddens, 1990; Lash, Szerszynski, and Wynne, 1996; Stirling, 1999). The factors driving these changes include:

- Greater access to information (e.g., through the Internet), allowing citizens unprecedented knowledge about government, industry, and research. As a result, risk-management errors and scientific controversies are more visible at stages in technologies' development where uncertainty is high (Commission of the European Communities, 2000; Rossi, 1997; UK Health and Safety Executive, 1999; USFDA, 2000).
- Regulators and industry have been faulted in major heath and environmental problems, leaving many parties skeptical of their motives and analytical procedures (Stirling, 1999). These crises include Chernobyl, Brent Spar, BSE in British (and, now, European and Japanese) beef, dioxin in Belgian chicken feed, and contaminated blood in France.
- As faith in professional risk managers has declined (Löfstedt and Horlick-Jones, 1999; Marris, Langford, and O'Riordan, 1996), the public has increasingly turned to NGOs, independent scientists, and the media for guidance. In Europe, Greenpeace has proven particularly effective (House of Lords, 2000), while often invoking a precautionary principle (Durodie, 1999). For example, Greenpeace has argued that, in marine environments, all persistent synthetic substances should be considered hazardous until proven safe, not just those appearing in high concentrations or with known risks.[3]

[3] The recent foot-and-mouth disease crisis is evoking criticisms of industrialized agriculture, as creating unrecognized uncertainties. The ensuing calls for return to simpler forms of farming are consistent with casting agriculture in terms where precautionary principles might apply.

At times, debates over the science relevant to specific regulatory contexts have become debates over science in general. Some critics claim that precautionary principles undermine science's role in regulatory decision making (e.g., Gray et al., 1991). Some proponents claim that science should be undermined, when it assumes inappropriate roles, such as claiming unwarranted certainty or injecting scientists' values in their analyses (Santillo et al., 1998; Santillo, Johnston, and Stringer, 1999). An intermediate position holds that science is essential for identifying potential risks. However, it often lacks the theoretical, measurement, and financial resources to achieve acceptable levels of certainty. Those challenges arise from their limited ability to measure exposures, characterize dose-response relationships, and estimate responses to complex mixtures.

Some observers point to a world of "post-normal science," with high stakes and uncertainty, beyond the capability of conventional policy analysis (Funtowitcz and Ravetz, 1990, 1994). Some environmental groups argue that this world requires an expanded role for NGOs, representing and interpreting precautionary principles. These groups do not dismiss science, but doubt its ability to resolve issues with great uncertainties and pervasive value conflicts. However, even those who acknowledge limits to conventional science may be uncomfortable with the transfer of power were NGOs made the arbiters of ambiguity (Durodie, 1999). Some U.S. critics also argue that businesses and governments may invoke precautionary principles to protect their markets from outside competition. They point to "precautionary" bans that fall heavily on U.S. products, such as GM corn and beef raised with growth hormones (Lynch and Vogel, 2000; Tait, 2001; Vogel, 1995). The Commission of the European Communities (2000) has recognized these possibilities, without offering a clear resolution.

The Regulators' Dilemma

Facing an increasingly distrustful public, some regulators have sought to increase their legitimacy by endorsing precautionary principles. A resolution of the Commission of the European Communities (2000, p. 8) states this aspiration as "to be in the future even more determined to be guided by the precautionary principle in preparing proposals for legislation and in its other consumer-related activities and [to] develop, as a priority, clear and effective guidelines for the application of this principle."[4] The inevitable price has been confrontations with industry and trade organizations (House of Lords, 2000; Rose, 1998).

According to the Commission, "... application of the precautionary principle is part of risk management, when scientific uncertainty precludes a full assessment of the risk and when decision makers consider that the chosen level of environmental protection of human, animal and plant health may be in jeopardy" (p. 13). The Commission postulates (pp. 18–20) the following general principles for measures (primarily prohibitions) applying the principle:

- Proportionality: "measures must make it possible to achieve appropriate levels of protection."
- Non-discrimination: "comparable situations should not be treated differently and … different situations should not be treated the same way."
- Consistency.

[4] Graham and Hsia (in press) and Weiner and Rogers (in press) discuss this more fully.

- Examination of benefits and costs: "a comparison must be made between the most likely positive or negative consequences of the envisaged action and those of inaction in terms of the overall costs to the community."
- Examination of scientific developments: "measures should be maintained as long as the scientific data are inadequate, imprecise, and inconclusive, and as long as the risk is considered too high to be imposed on society."

Conclusion

Germany and Sweden had early success in adopting precautionary principles and applying them in ways that brought generally accepted results. These accomplishments came in circumstances with relatively high social consensus and relatively low (recognized) scientific uncertainty. Neither condition is fulfilled in many current controversies involving precautionary principles. The controversy over GMOs in agriculture and foods, which often centers on precautionary principles, offers a concrete context to consider the roles of such principles.

GENETICALLY MODIFIED ORGANISMS (GMOS) IN AGRICULTURE

The Technology

Drugs developed with recombinant DNA technology have been on the market for some time, recently generating little controversy. More recently, agricultural applications have emerged, with novel genes being added to various crops, including corn, soy, cotton, tobacco, potatoes, sugar beets, and canola. The vast majority of these crops are GM herbicide-tolerant (GMHT), Bt-protected, or "stacked" (with both properties). GMHT crops tolerate a specific, non-selective herbicide (often sold by the firm creating the crop), intended to kill all plants but the protected crop. Bt-protected crops contain a gene, from the bacterium *Bacillus thuringiensis*, which produces a protein toxic to certain pests—and some other insects. Other GM crops under development have potentially healthful traits, such as beta carotene in "golden" rice and mustard. There are also transgenic fish, mammals, insects, and trees (i.e., ones with genes from other organisms), although none are known to be in commercial use.

The introduction of GM crops is among the most rapid and widespread agricultural developments in human history. Although China began growing GM tobacco commercially in 1988, GM crop usage became widespread only in the mid-1990s. From 1996 to 2000, global transgenic crop area increased from 7 million to 98.6 million acres. Although at least 13 countries reported commercial use in 2000 (James, 2000; USDA, 2000), 75 million of those acres were in the United States.

Potential Risks

Health

Two risks to human health receiving particular attention are antibiotic resistance and allergic reactions. A common technique for creating GMOs links a gene conferring antibiotic resistance to the desired gene. Antibiotics eliminate all cells lacking the resistant gene and desired trait, both of which remain in the GMO. One possible risk with this procedure is antibiotic resistance spreading to harmful bacteria. Although there is no evidence of such spread, it would be difficult to identify any specific contribution of GMOs to the general increase in antibiotic-resistant bacteria. These concerns have led to primary reliance on a resistance marker for which bacterial resistance has been widespread for some 20 years (Roush, 2002).

Transferring genes from organisms of known allergenicity to new plants creates risks for sensitive individuals who do not suspect them there. Those risks led to rejecting a GM soy modified to contain a brazil nut gene (Nordlee et al., 1996). Greater uncertainty arises when GM foods include compounds previously unknown in foods, such as Bt proteins. Aventis's StarLink corn was approved solely for nonfood use because its Bt protein (Cry9C) has properties similar to those of known food allergens (molecular weight, stability under gastric conditions). Non-dietary allergenicity is also possible: Skin-test sensitivity to Bt increased from 8 percent to 70 percent among crop workers after 3 months' picking crops sprayed with it (Bernstein et al., 1999).

Environment

Three of the possible environmental risks of GMOs have attracted particular attention: hybridization, harm to non-target species, and ecosystem disruption. Hybridization may occur between GM crops and wild plants or other crops (e.g., through blowing pollen). As a result, weedy natural relatives of commercial plants can acquire the transferred traits, making them more competitive (Ellstrand and Schierenbeck, 2000). In Canada, cross-pollination among three herbicide-resistant strains of canola, two GM and one conventional, has produced strains resistant to three herbicides: imidazoline, glyphosate (Roundup), and glufosinate (the herbicide used on Aventis GMHT crops) (Hall and Hauck, 2000). In addition to reducing agricultural yields, such hybrids could diminish natural plant diversity by competing or hybridizing with wild species. For example, one study found that Bt canola survived better in grassland areas (outside of cropland), possibly because the Bt toxin protects it from natural enemies (Nigh et al., 2000). Despite a national moratorium in Mexico, a study reported GM corn growing widely in two Mexican states that are the center of diversity of teosinte, maize's wild ancestor (Dalton, 2001)—a claim that has been hotly disputed (Christou, 2002), with further controversy in the works.

Such habitat changes can, in turn, affect wildlife. Bt crops are meant to kill lepidopteran (moth and butterfly) pests, but might also affect non-target species (Hilbeck et al., 1998). Unlike sprayed Bt, which degrades quickly, Bt crops continually produce the toxin. Exuded by their roots, Bt proteins remain active by binding to soil particles (Saxena, Flores, and Stotzky, 1999; Tapp and Stotzky 1998). Pollen drift from Bt corn may threaten monarch butterflies (Losey, Rayor, and Carter, 1999; Pimentel and Raven, 2000). Assessing this risk, with appropriate spatial and temporal variation, requires geographically extensive, long-term studies of the interactions among Bt corn, milkweed, monarchs, and other elements of agroecosystems that mediate the impact of Bt and affect monarchs independently. Cornfields are important habitat for milkweed, monarchs' sole food source (Hartzler and Buhler, 2000). The relative productivity of nonagricultural areas for monarchs, compared to cornfields, varies regionally by two orders of magnitude (Oberhauser et al., 2001). Milkweed dusted by Bt pollen under field conditions reduced monarch larvae survival and growth with one strain of Syngenta's Cry1Ab corn, which should be phased out by 2003 (Jesse and Obrycki, 2000; Sears et al., 2001). Monarchs caged on milkweed plants in fields of Syngenta's Bt11 experienced marginally insignificant ($p = .07$) reductions in survival to adulthood (Stanley-Horn et al., 2001). Under natural conditions, the larvae "may be exposed to the biologically active Cry1Ab in pollen for a longer period than 4 or 5 days," the duration of the Bt11 study. Non-Cry1Ab strains were not found to have negative impacts on monarchs. These studies show some of the uncertainties in the science needed to predict the effects of a novel crop in an intricate ecosystem. Even if these fears are successfully allayed, there will be discomfort in some quarters that some of the basic research (e.g., on monarch habitat) came after the introduction.

As another example of the subtlety of these interactions, a modeling study (Watkinson et al., 2000) concluded that GMHT sugar beet could dramatically reduce populations of skylarks (and other granivorous birds) by reducing seeds of the weed *Chenopodium album*, a critical food source. The effects would be largest on currently weedy farms.[5] Weed reduction may also alter the availability of insect prey. Lepidoptera, the direct target of Bt crops, are important foods for farmland birds (e.g., Wilson et al., 1999). Other invertebrates may also be affected by changes in weed communities.

Public Concerns

The jury is still out on many of these possibilities. However, GMOs appear to have many properties often associated with public concern, in "psychometric" studies of risk (Slovic, 2000). Jenni, in a 1997 review, cites 57 such studies which find people particularly averse to risks rated highly on scales that are often grouped as evoking feelings of *dread* and *unknown* (see Table 2.) In a 1980 study (reported in Slovic, Fischhoff, and Lichtenstein, 1985), "DNA technology" was rated almost as poorly as nuclear power. The thinking (and feeling) underlying such beliefs might be seen in the words of John Beringer (1999), chairman of the UK Department of Environment, Transportation and Regions: "It is incomprehensible to me that some of the first fruits of a new and potentially very frightening technology should have been herbicide-tolerant crops and crops carrying genes that confer resistance to important clinical antibiotics."

There is no simple relationship between such judgments and actions (Flynn, Kunreuther, and Slovic, 2001; Slovic, 2001). The United States experienced early public concern about GMOs, followed by a relatively quiet period and a modest recent rise in interest. In Europe, concern seems to have escalated steadily from the early 1990s (Gaskell, 2000). Whether a technology's risks are noticed at all depends on whether the news media and its opponents draw attention to them. That, in turn, depends on their intuitive theories of their audiences' interests, as well as the industry's own actions, raising or allaying concerns. In the United States, the industry quietly secured early regulatory approval, while experiencing few public embarrassments. In Europe, the industry was quickly embroiled in contentious regulatory proceedings, played out against continuing turmoil in the European food scene and jockeying for economic advantage among the member states and their trading partners.

Even deeply held values require avenues to reveal themselves in action. With GMOs, individuals' options range from rejecting GMO foods, to avoiding investments in GMO firms, to direct actions against GMO crops. Such non-governmental activities shape the risks and benefits that policymakers must balance, when regulating a technology—and suggest the concerns that a precautionary principle might address. (Fischhoff and Fischhoff [2001] and Fischhoff, Nadaï, and Fischhoff [2001] review them more thoroughly.)

[5] For a critique of their model, see Firbank and Forcella (2000), scientists working for the UK Field Safety Evaluations (FSEs) and the U.S. Department of Agriculture (USDA).

Table 2. Properties of technologies associated with risk aversion in psychometric studies of risk.

Factor 1: Dread Risk
Globally catastrophic
Dread
Severity
Uncontrollable
Irreducible
Increasing
Affects me
Affects future generations
Inequitable
Involuntary
Factor 2: Unknown Risk
Unknown to science
Unknown to exposed
Unobservable
Delayed effects
New

Adapted from Slovic, Fischhoff, and Lichtenstein (1985). When a third factor emerges, it typically reflects the number of those exposed to the risk.

In the United States, "socially responsible" mutual funds and managed accounts control some 13 percent of investments (Stanton, 2000). Fund operators and advisors such as Calvert and New Alternatives may exclude firms involved with GMOs when making investments, thereby restricting their access to capital markets. In the past year, at least 19 U.S. companies (e.g., Kellogg, ADM, Safeway)[6] have faced shareholder resolutions on GMOs, filed by religious orders, investment clubs, or asset managers (e.g., Citizens Fund, Walden Capital, Trillium). Although these resolutions have never come close to passing,[7] the commitment behind such activism may send a signal to management. Related signals, whether coming directly from consumers or indirectly through regulatory processes, have led many firms to exclude GM foods from their products. These range from Hain's Little Bear snacks to Kirin Brewery beer to all foods produced by Novartis (itself a major GMO developer, which spun off its agricultural biotech operations as Syngenta, in 2000).[8]

The deepest commitment might be direct acts of vandalism against GM test sites, commercial crops, or research facilities. Between 1987 and June 2001, there were at least 133 such actions (as well as actions like preventing ships with GMO loads from docking, public demonstrations, illicit labeling in supermarkets, and throwing pies at GMO proponents).[9] About half the direct actions occurred in Europe and a third in North America, with others in Asia (South Korea, New Zealand, Australia, India) and Brazil. The most common institutional targets were universities (31 times),

[6] List and statistics available from the authors.
[7] For the nine resolutions that came to votes, the mean support was 3.8 percent (range: 2.2–8.2 percent). Resolutions for five companies (Coca-Cola, PepsiCo, Philip Morris, Quaker Oats, and Kroger) passed the 3 percent threshold, resulting in automatic resubmission in 2001.
[8] A list of 56 firms, with the date and scope of each ban, is available from the authors.
[9] These incidents are documented in a research note available from the authors, categorized by nation, crop(s), activist group, company or companies affected, government or university affected, status of the target as GM or non-GM, date, cost, and extent of crop damage (number of plants or acres).

Monsanto (19), government sites (12), Novartis (9), and Aventis (or its predecessor, AgrEvo, 14). The 45 groups identified as responsible for these acts range from ephemeral cells to major NGOs, like Greenpeace. They bring unwanted attention to the industry and, for less involved citizens, may give cause to wonder: Why are the activists so worked up over these products? Although the total reported costs (US$5 million, in 22 incidents) are small, relative to the size of these industries, they increase the cost of doing business. When field-test plots are destroyed, product development is delayed, as is research that could reduce uncertainties (Firbank, 1999, 2000).

Quality of the Relevant Science to Addressing Public Concerns

Although there are many studies of the environmental impacts of GM crops, most appear in the gray literature of technical reports, produced for industry and submitted to regulators. A recent comprehensive review (Wolfenbarger and Pfiher, 2000) found only 35 peer-reviewed articles with the level of scientific credibility that might be demanded of evidence regarding public risks (even if firms might demand less for internal decisionmaking—and even avoid peer review for proprietary reasons). The *New York Times* (Yoon, 2000, p. A31) summarized the review as showing that

> simple conclusions cannot yet be drawn because the critical studies have not yet been done;... scientists still know little about the likelihood even of the environmental threats of greatest concern. Also, almost no studies have been published documenting ecological benefits ... . [C]urrent data indicate that assessing ecological risks is likely to be complex, with risks varying among crops, even among strains of a single crop, between environments and over time. Some risks [the authors] say, may be so difficult and time-consuming to assess as to be effectively unknowable.

Industry and NGO representatives interviewed by the *Times* endorsed the competence of the review, but drew very different practical conclusions. The chief technical officer of a prominent biotechnology firm "played down the findings ... saying that, in several years of commercial use, no ecological problems had yet been shown." A critic commented, "You come out of this with a strong sense that we don't know very much about the risks and benefits. If we don't know, why are we doing this?" (Yoon, 2000, p. A31) Thus, the review provided fodder for both sides, showing the inconclusiveness of claims regarding ecological harm or ecological good, depending on what they choose to emphasize. Under these circumstances, regulatory decisions inevitably reflect a political/ethical choice regarding the burdens of proof borne by a technology's proponents and opponents.

Such uncertainties often accompany the interactions between a cutting-edge technology and complex natural and human environments. Table 3 shows some of the scientific issues surrounding the allergenicity of StarLink corn. Effects issues reflect uncertainties regarding physiological responses to the introduced Cry9C protein and, to some extent, allergenic processes in general. Exposure issues reflect environmental processes (e.g., pollen drift) like those discussed earlier, but also uncertainties in industrial food and agriculture management. These systems cannot currently track and segregate specific crop strains through their life cycle, from seed production to planting to food preparation, consumption, and disposal. Table 4 shows some events in a mishap, whereby StarLink, a stacked corn approved only for domestic animal consumption, found its way into the human food chain. As research accumulates regarding StarLink's allergenicity, its effects may prove sufficiently minor that exposures to it become uninteresting. However, the StarLink experience has shown

Table 3. Some uncertainties regarding the allergenicity of Cry9C StarLink Corn.

Exposure
- Percentage of buffer corn producing Cry9C due to cross-pollination from StarLink
- Variations in Cry9C protein concentration in corn, grain supply, and food products
- Effect of food processing on Cry9C concentration and stability
- Concentration in diets of infants, ethnic groups
- Presence of StarLink in foods consumed by people reporting StarLink reactions
- Percentage of StarLink harvest that entered human food supply

Effects
- Potential glycosylation of Cry9C protein
- Potential for Cry9C-specific IgE response in people reporting StarLink-associated illnesses
- Appropriateness of rodent models of allergenicity
- Detectability of processed, denatured, or degraded Cry9C (with current analytical methods)
- Protein characteristics inducing allergenicity
- Implications of in vitro digestibility studies, given variability in human gastric conditions and food transit time through stomach
- Relevance of immune response to bt spray for evaluation of potential Cry9C allergenicity

Sources: U.S. Environmental Protection Agency (2000); U.S. Environmental Protection Agency Scientific Advisory Panel (2000).

the complexity of controlling and estimating exposure processes, for cases where they do matter (e.g., terrorist contamination of the food chain).

Unless their decisions reflect risks alone, policymakers will consider the other side of the ledger. Although attention has focused on GMOs' potential risks, uncertainties surround their benefits as well. The primary economic uncertainties concern pest resistance, yield drag, and price premiums for non-GMO crops (reflecting consumers' preference and distributors' cost of separation). Both Bt and GMHT crops can violate the integrated pest management tenet of not relying on a single pesticide, lest that promote resistant plant and insect pests. Critics worry that resistance will arise more quickly with Bt crops than with Bt sprays, because Bt crops are used on greater acreage and exert continual selection pressure from all plant parts. U.S. Environmental Protection Agency (USEPA) has mandated planting 4 to 20 percent non-Bt crops as "refuges" for non-resistant pests, intended to mate with pests from Bt fields and slow the rise of resistance. This strategy, too, faces many uncertainties, creating scientific interest and regulatory frustration.[10] Resolving them requires biological, ecological, and social science research (e.g., on farmers' compliance with recommended cropping strategies).[11]

[10] If the genes for resistance have sufficiently low initial frequencies and are inherited recessively, then the refugia could prevent evolution of resistance indefinitely. Initial allelic frequencies for bt resistance in pests are estimated at 1/100 to 10^{-13}, "which is a scientific way of saying 'we don't know'" (Tabashnik, 1997). Bt resistance is recessive in the pink bollworm, a cotton pest (Liu et al., 1999). However, lab research using bt spray indicates dominant resistance in the European corn borer (ECB). If this is correct, then current refugia may not work for ECBs, because the offspring of resistant and non-resistant ECBs would be resistant (Huang et al., 1999). The Huang et al. study has been criticized for using bt spray rather than plant-produced bt (Shelton and Roush, 1999; Shelton et al., 2000).

[11] For example, among 400 Ontario corn farmers in 1999, 13.5 percent reported planting bt corn on more than 80 percent of their acreage, despite standards dictating that refuges be at least 20 percent of corn acreage. Refugia requirements were unknown by 22.5 percent of farmers, while 24.7 percent were unsure how many non-bt acres they were willing to plant. "Plant some non-bt corn" was how 42.2 percent of farmers described their understanding of resistance management (Lastovic and Powell, 1998; Powell, 1999).

Table 4. Some events in mishap involving Aventis StarLink Corn.

April 10, 1998. USEPA grants Aventis temporary tolerance exemption for StarLink.
August 2000. USEPA reports that “strict guidelines have been imposed to prevent Cry9C-containing corn from entering the human food supply.” It “is reviewing a petition from Aventis” for StarLink use in human food.
September 18. The NGO Genetically Engineered Food Alert announces tests showing StarLink I tacos. Sold under the Taco Bell label (a Tricon Global Restaurants subsidiary), the tacos were supplied by Kraft Foods (Phillip Morris), produced by a Mexican PepsiCo subsidiary, using corn from Azteca Milling (Gruma SA and Archer Daniels Midland joint venture). Aventis CropScience, a joint venture of Aventis and Schering AG, claims that the testing lab, Genetic ID, earlier falsified a report on GM corn in a Japanese produce; Genetic ID defends itself.
September 22. Confirming contamination, Kraft recalls 2.5 million boxes of taco. It calls for official testing standards, mandatory safety reviews of new GMOs, and an end to animal-use only crop approvals.
September 29. Aventis agrees to pay for purchase of segregated StarLink from farmers at a $0.25/bu premium above animal feed prices.
October 2. FDA starts testing foods for StarLink.
October 12. Aventis voluntarily withdraws StarLink registration.
October 13. Mission Foods recalls all yellow corn tortilla products from 35 companies. Safeway says that Mission had previously assured it that there was no contamination.
October 17. ConAgra closes a mill due to possible StarLink contamination. The *New York Times* reports that many farmers were unaware of StarLink restrictions, while others were told that approval for food use was imminent.
October 19. About half of grain elevators that received StarLink report having sent it on for human uses. Aventis agrees to buy StarLink-contaminated corn.
October 20. Cargill admits having unapproved corn in its supplies, but says that it has resolved the problem. It says that testing for StarLink had only recently become possible. Tyson Foods stops feeding chickens StarLink.
October 21. Kellogg closes a plant because of StarLink contamination.
October 25. Japanese NGO No GMO Campaign announces tests showing illegal StarLink in corn flour. Aventis requests EPA approval of four years of StarLink food use, after which it will be gone from food chain.
October 27. USDA reports having located 78.8 of 80 million bushels of StarLink.
November 1. FDA reports recall of over 300 corn-based products due to potential contamination.
November 15. USDA and Japan start joint StarLink testing program.
November 21. Aventis announces that, since 1998, “an unknown proportion” of non-StarLink seed distributed by Garst has contained the gene for StarLink’s Cry9C Bt protein.
December 5. USEPA’s independent Scientific Advisory Panel urges further study of uncertainties about StarLink, including its relevance to allergic reactions claimed by 14 people.
December 18. Schering AG estimates StarLink-related costs at $49–58 million in 2000.
January 16, 2001. Aventis says that its total costs related to the StarLink mishap will be “significantly below” $1 billion.
February 21. USDA and Japan step up StarLink testing efforts after it is found in several shipments that had undergone USDA testing.
March 1. Aventis reports having purchased 94 million bushels of StarLink-contaminated corn, found in 285 barges, 15,000 railcars, and 28,000 trucks.
March 18. Aventis estimates quantity of StarLink contaminated grain at 430 million bushels.
July 27. USEPA’s Scientific Advisory Panel recommends against temporary approval of a 20-ppb tolerance level for StarLink, based on the conclusion that there is a “medium likelihood” of allergenicilty

Transgenic crops have sometimes shown reduced yields (Benbrook, 1999; Hartzler, 1997). The reasons for this yield drag are poorly understood, but may include seed impurity, unintended changes caused by the novel genes (pleiotropy), and reduced attention to yield improvement (relative to the development of conventional crops). Yield drag occurs indirectly when herbicide spray drifts from GMHT-resistant crops to non-GMHT ones. Predicting that drift requires estimating weather, weed emergence, and spray patterns, among other things (Owen, 1998).

Considering the slow pace of publicly available research and the complexity of the problems, significant uncertainties are likely for a long time. The United Kingdom only recently began a 3-year program of farm scale evaluations (FSEs) of plant, invertebrate, and microorganism biodiversity in fields sown with GMHT and conventional canola, maize, and sugar beet (Firbank, 1999, 2000). In 2000, the British Trust for Ornithology (Clark, November 2000, personal communication), in conjunction with the FSEs, began studying GMHT effects on bird ecology. The USDA annually earmarks about $1.5 million for its Biotechnology Risk Assessment Research Grants Program.

In the meantime, any regulatory action effectively takes a position on precaution. For example, USEPA (2000) concluded that hybridization of Bt crops and other U.S. plants would have a "neutral effect" on the recipient wild plants and was not "a significant agricultural or environmental risk" and that Bt crops are benign for non-target (i.e., non-pest) species. Because EPA "knew that Bt was toxic to Lepidoptera," it did not require testing on non-target Lepidoptera, assuming that non-target species "would not be exposed to Bt protein." Critics claim that USEPA has shown insufficient caution, pointing to the many topics that have yet to be studied and the residual uncertainties regarding those that have. One recurrent concern for critics is the low statistical power of many studies, reducing the chances of finding problems (e.g., Marvier, 2001). Small samples may reflect researchers who do not really want to find problems, want to spread limited resources over many topics (Page, 1978), and overestimate the power of small samples (Tversky and Kahneman, 1971). Reducing uncertainty incurs both direct costs (doing the research) and indirect costs (waiting for results).

Invoking Precautionary Principles

Regulators' actions reflect the fragmented reality that they must manage. As seen, the science regarding GMOs' risks (and benefits) often lies in many disconnected pieces, spread over research communities unfamiliar with one another's work and evidentiary standards, much less able to integrate their research into comprehensive integrated assessments (Dowlatabadi and Morgan, in press; Fischhoff, 2000). The parties to policy making often come from mutually suspicious communities, with different backgrounds and incentive structures. The regulators themselves are scattered over multiple countries, and agencies within them.

Typical of this fragmentation is an early U.S. Food and Drug Administration (USFDA, 1992) ruling that GM foods are, in principle, substantially equivalent to other foods that "have been widely recognized and accepted as safe…[and will not] have a significant effect on the human environment." That ruling's definition of "genetic modification" made no distinction between conventional breeding and modern biotechnology. As a result, FDA could point to the long "record of safe development of new varieties of plants," for which "the FDA has not found it necessary to conduct, prior to marketing, routine safety reviews." Had FDA defined GM ingredients as food additives, it would have required safety and environmental impact assessments, rather than just voluntary safety testing and informal consultations. As a result, this critical venue provided no forum for discussing issues important to some parties, risking the impression of a cozy, lax decision-making process. Eight years later, in May 2000, President Clinton announced that companies would soon have to provide FDA with prescribed safety data 120 days prior to market entry of novel GM foods—although without prescribing a precautionary (or any other) decision rule.

Table 1 shows some of the international agreements citing a precautionary principle. The viability of each depends on developing a consensual interpretation of its specific notion of precaution. That process is predicated on deciding that it is needed at all. The World Trade Organization's Agreement on the Application of Sanitary and Phytosanitary Measures (SPS) states that "no Member should be prevented from adopting or enforcing measures necessary to protect human, animal or plant life or health," provided those measures do not constitute "unjustifiable discrimination between Members where the same conditions prevail or a disguised restriction on international trade." Defining this precautionary principle means clarifying "measures necessary to protect." International discussions have, instead, focused on clarifying "unjustifiable discrimination"—responding to GMO proponents' claim that precautionary policies based on unproven risks create illegal trade barriers. Thus, uncertainty that could be used to justify precaution is invoked to preclude it. Here, too, the fundamental question is who bears the burden of proof.

Under the SPS, protective measures limiting trade must be based on "sufficient scientific evidence," with the exception that, "where relevant scientific evidence is insufficient, a Member may provisionally adopt protective measures. To take such measures, a state must show that scientific evidence is inconclusive, have some basis for its concerns, continue to pursue scientific assessment, and revise the policy based on new findings" (Article 5.7). Thus, it endorses a strong role for both science and precaution, without using the latter word or setting practical guidelines for the "protective measures." The SPS also allows Members to set the "level of protection deemed appropriate," defined as the "acceptable level of risk." Allowing some states to be more risk averse than others effectively concedes variability in precautionary standards.

The history of other international agreements shows similar challenges to creating a stable forum with accepted deliberative rules, the necessary precursor to deriving a consensual precautionary principle. For example, the 1999 Cartagena meeting attempted to produce a biosafety protocol on prior informed consent for international trade in GMOs, as part of implementing the 1992 Convention on Biodiversity. It foundered over applying the precautionary principle and identifying the releases to be covered. The Cartagena Protocol finally passed in Montreal, in January 2000. Intervening events (e.g., the Seattle WTO protests, product labeling demands) brought some convergence among the parties. However, the Protocol still finessed many issues, such as its relationship to other agreements (Gupta, 2000).

DEVELOPING A SUSTAINABLE PRECAUTIONARY PRINCIPLE

The Rhetoric of Precaution

Discussions of precautionary principles are often cast in extreme terms, caricaturing opponents and proponents. Some rhetoric is inevitable, given the stakes involved. For proponents, precautionary principles offer a hope of avoiding serious, perhaps irreversible damage to health, safety, and the environment. For opponents, they represent an assault on science, reason, free trade, and commerce. Members of both camps may have material stakes as well. Under these circumstances, rhetorical excesses are understandable. Nonetheless, they muddy the picture, in a situation where achieving clarity is already difficult. For example, critics may enlist otherwise uninvolved scientists by claiming that all science is threatened, when precautionary principle advocates question specific studies. If these scientists dismiss concerned citizens as irrational (ignorant, hysterical, etc.), they further undermine public trust in their work and motives (U.K. Parliamentary Office of Science and Technology, 2001; U.S. National Research Council, 1996). For their part, precautionary principle proponents may strategically cast a wide net, indiscriminately grouping benign and troublesome forms of the technology. They may have unintended help, when advocates of a troublesome variant group it with benign ones, in hopes of innocence by association (e.g., associating GMOs motivated by profits with ones addressing Third World nutritional deficiencies) (e.g., Pollan, 2001).

Nonetheless, many controversies reflect more than just motivated misunderstanding. In an effort to clarify boundaries, the Commission of the European Communities (2000, p. 15) recently required "a true level of uncertainty," before invoking a precautionary principle. More specifically:

> Recourse to the precautionary principle presupposes [a] identification of potentially negative effects resulting from a phenomenon, product, or process and [b] a scientific evaluation of the risk which because of insufficiency of the data, their inconclusive or imprecise nature, makes it impossible to determine with sufficient certainty the risk in question.

Even that clarification leaves much room for the interplay of science, commerce, and politics. The more perilous a technology seems, the greater the scrutiny of the relevant science. If the science is strong, then conventional analysis may satisfy policymakers' needs. They can, then, focus on balancing the expected benefits, risks, and other costs that the analyses describe. The weaker the science, the more likely the technology is to have "a true level of uncertainty." Scientific weakness may mean failing to resolve issues or neglecting them entirely (Fischhoff, 1977). When it ignores topics, the research community must show that the gaps reflect neither incompetence (not seeing the issues) nor complicity (not wanting to see them).

Even if uncertainty falls below the critical "true level," it may take a concerted effort to keep it there. Innovation may render existing research decreasingly relevant to the technology actually being implemented. Environmental impact analyses lose currency when the focal environment changes because of natural processes, other technological impacts (e.g., climate change, pesticide bioaccumulation), or other anthropogenic pressures (e.g., deforestation, sprawl, clearing hedgerows). An analysis may prompt changes that limit its shelf life, if risk managers reduce the risks it reveals. Risk analysis is often used probatively, to demonstrate absolute risk levels that comply with regulatory standards. However, its intellectual origins are comparative analysis of alternative designs, looking for problems and solutions. Risk managers may have to choose between living with known problems and accepting increased uncertainty, until analysis catches up with system improvements. Nonetheless, a reputation of aggressively looking for problems may reduce fear of hiding true uncertainties.

Conditions for Trust

Within well-established scientific communities, addressing mature problems, with widely accepted methods, stringent procedures ensure the credibility of results—and impose strong sanctions for detected violations. Those norms allow "normal" science to proceed. Arguably, citizens might want similar conditions fulfilled, if they are to trust the science underlying a policy.

Table 5 offers one specification of the conditions for trust, based on those that specialists afford one another in healthy technical communities. They include scientific and social conditions, referring to the content and conduct of science, respectively. Each category includes conditions associated with general approaches and specific applications. When considering the science in a specific analysis, a specialist would want to understand the underlying models, review parameter estimates, request sensitivity analyses, and double-check results. Professionals can exercise such case-specific due diligence because they know, in general terms, why those methods are currently favored, what basic science supports them, which (often unwritten) auxiliary assumptions they incorporate, and when modeling makes sense at all.

On the social level, trust increases when specialists know the researchers, find their concerns explicitly recognized in the work, receive rewards for participation, and are treated respectfully. More generally, trust increases with feeling part of the analytical enterprise, with a hand in setting its norms, a stake in its success, and accommodation to the limits of analysis.

Precautionary Communities

As mentioned, technical communities often meet these conditions. Members have similar training and outlook. They extend one another professional courtesy, and behave predictably. They respect one another's expertise, even when they dispute

Table 5. Conditions for public trust in risk analyses.

Scientific Conditions

Immediate
- Familiarity with specific models
- Familiarity with specific inputs
- Access to sensitivity analyses
- Ability to double-check

Ambient
- Familiarity with historical development
- Familiarity with underlying science
- Familiarity with auxiliary assumptions
- Familiarity with analytical perspectives

Social Conditions

Immediate
- Familiarity with analysts
- Recognition by analysis
- Reward for participation
- Respectful treatment

Ambient
- Familiarity with analytical community
- Influence on regulatory process
- Long-term involvement
- Accommodation with process

results and compete for resources. This is the behavioral mountain that citizens must climb, or scientists must level, when complex, novel problems bring their communities together and trust must be established.

The early Swedish and German experience with precautionary principles approached these conditions for trust (for Sweden: Kelman, 1981; Lundqvist, 1980; for Germany: Brickman, Jasanoff, and Ilgen, 1985). The focal technologies were threatening and uncertain enough to generate precautionary concerns. However, the communities were relatively small and shared common values (8 million Swedes; two south German provinces with about 20 million people) and political processes that included the critical parties. These circumstances facilitated seeking common ground regarding both the issues and the tradeoffs. Fortuitously, enough deals could be cut for the experiments to continue.

Scaling up to larger arenas proved more difficult. The Swedish precautionary principle was more ambitious than the Germans would accept. The German principle, in turn, achieved less consensus at the European level. Increasing the size and heterogeneity of the communities involved interfered with creating the scientific and social conditions needed for a shared view of the issues. It became harder to ensure equal access, with parties ranging from small-country NGOs to large-country industries. Personal relationships provided fewer back channels for assessing other parties' intent and credibility. The broader stage increased the intrusion of other issues unrelated to understanding and evaluating specific technologies (e.g., trade, electoral politics).

Thus, scale undermines the credibility of conventional analysis (and normal science). It raises concerns about the objectivity of analyses, in the sense of values affecting their specification (e.g., how "risk" is defined) and scientific judgment affecting their execution. These concerns encourage seeing something akin to "a true level of uncertainty." Precautionary principles then become ways to rein in policy-making processes that are moving too fast, without securing the informed consent of those they affect. Some players will, of course, only endorse processes that produce the policies that they want (or, at least, provide a personal hearing). Others, though, might accept an appropriately constituted deliberative community of stakeholders, entrusted with resolving otherwise moot issues—such as what represents a true level of uncertainty. Such processes are, increasingly, advocated by national advisory bodies, for broad classes of health, safety, and environmental issues (e.g., Canadian Standards Association, 1997; U.K. Royal Commission on Environmental Pollution, 1998; U.S. Congressional and Presidential Commission on Risk, 1998; U.S. Institute of Medicine, 1998; U.S. National Research Council, 1996).

These proposals reflect the convergence of several processes. One is direct political pressure for greater inclusiveness. A second is a desire to avoid stalemates over issues that seem to defy the conduct of mutually acceptable analyses. A third is the growing tendency to view positions on novel issues as "constructed" from basic values, rather than "read off" from a universal utility function (e.g., Fischhoff and Manski, 1999). Well-mediated social interactions can facilitate the construction process by exposing alternative perspectives and simulating the social construction of values. A fourth contributing process is growing scientific understanding of how to manage such deliberations (e.g., select participants, moderate meetings, communicate risks, elicit values, summarize conclusions), and create conditions for trust like those of Table 5. Some of these conditions require long-term associations (with the problem and the other players). As a result, it could pay to create deliberative communities in advance of testing them in the cauldron of specific controversies. Respectful interpersonal relationships should increase the chances of resolving the ambiguity surrounding precautionary principles (Thompson, 2000).

Even if other stakeholders agree to such deliberations, some technical specialists may object. Consultation complicates their already difficult task. It may require social and institutional skills outside their training and inclination. It acknowledges an uncomfortable subjectivity in their science. In return, it offers the hope of helping scientists to produce more trusted and relevant research, with no more reliance on precautionary principles than the underlying uncertainties warrant. Analogous gambles face the other players (e.g., industry, activists, regulators), when comparing deliberation with the alternatives. The legitimate aim for deliberation is fewer, but better conflicts: avoiding needless disagreements, while sharpening genuine ones.

A Tale of Two Technologies

From these perspectives, GMO technologies face serious challenges. Their geographic spread (millions of acres, in countries around the world) means being judged by diverse stakeholders, with little direct interaction. Their risk attributes make them candidates for fundamental objections, should they attract attention. Their novelty, complexity, and diversity stretch scientific resources for reducing uncertainties or even for devising ways to mitigate well-understood risks. A rapidly moving, multidisciplinary science complicates communication, even among scientists. As a result, creating a community of understanding challenges the design of national and international regulatory bodies, and of the analytical professions serving them. Battles over precautionary principles are symptoms of institutional failure. Their resolution offers an opportunity to advance—and define—the frontier of orderly policy analysis and management.

As the institutions evolve, the political struggle continues. The parties' actions will affect both their own causes and the chances of joint resolution. In the United States, the industry is sharing more of the data submitted to regulators, as well as conducting a $50 million advertising campaign and lobbying intensively. These latter actions may not look like community building, however accurate their content. The industry has also chosen to present a solid front, defining the technology very broadly, grouping products that pose very different tradeoffs and uncertainties. That strategy encourages either broad acceptance of the technology or broad imposition of precautionary principles (Fischhoff, 1983, 1984).

The technology's opponents take analogous gambles. They may invoke deliberately vague precautionary principles, hoping to make themselves the arbiters of precaution. Like their industry counterparts, these strategists may find short-run succor in a fragmented decision-making process. Over the long run, though, their credibility may suffer, if they seem to be adopting inconsistent standards, without articulating a coherent division of labor between precautionary principles and conventional analysis. Over time, their energies may be drained by monitoring adherence to imprecise principles.

In choosing strategies, GMO partisans may wish to consider possible analogies with nuclear power. Two generations ago, it, too, was a highly innovative technology, whose advocates made great promises, while hoping to create sympathetic regulatory institutions. Its critics saw threats to fundamental life systems, with great uncertainty surrounding critical risks. Industry responded with the innovative intellectual technology of probabilistic risk analysis (U.S. Nuclear Regulatory Commission, 1974). However, its initial analyses lost credibility when independent reviews found that they had understated the uncertainties and events showed critical omissions (e.g., human factors at Three Mile Island [Lewis, 1980] and Chernobyl). The industry sometimes lost trust by defining problems narrowly and solutions broadly—saying, in effect, "We are fixing this specific problem, and nothing, even remotely like it, will ever happen again."

Over time, a patchwork of solutions grew into increasingly sophisticated understanding of risks and control strategies. However, there was little comparable progress in developing deliberative bodies.[12] Without them, citizens have difficulty establishing enough trust in conventional analyses to determine whether their precautionary concerns have been satisfied—and the industry is less able to develop and evaluate effective strategies. Communication may be limited to locales where industry and citizens naturally interact, leaving a deliberative void for technologies with global consequences.

Whatever the nuclear industry's future, its present falls far short of its founders' dreams. Publicly one can hardly even broach a possible role in reducing the environmental risks of global warming—whereas the technology was part of a precautionary solution in early 1970s West Germany. The technology's subsequent failure occurred despite having powerful economic and political supporters. They risked all, by presenting a common front, combining plants varying in technology and management philosophy, and by relying on analytical procedures stretched to their limits (and perhaps beyond). This could be the future for GMOs: relying on analysis, rather than deliberation; achieving important applications, after protracted struggle; but failing to fill many possible niches. Finding the "best buys" among GMOs will require institutional and intellectual innovation, to accommodate precautionary concerns, in mutually respectful ways. That might require sacrificing parts of the industry, so that others might live.

OPPORTUNITIES—AND CHALLENGES—FOR POLICY RESEARCH

Calls for, and against, precautionary principles raise fundamental issues of policy analysis and process. Addressing them raises opportunities, and challenges, for policy research.

At times, proponents of precautionary principles "just" want greater caution. In well-formulated analyses, that desire might be captured by developing ways to incorporate deep feelings of risk aversion, such as that created by fears of irreversible damages. With rapidly evolving technologies, and accompanying research, however, formulating such analyses may be the larger challenge. The approved technology may differ from the one that was analyzed. Even if the technology is stable, unanticipated effects and interactions may arise, defying systematic updating. As a result, the terms of analysis may be vague, leaving people nervous about just what deal they are signing (Fischhoff, 1994). Addressing such ambiguity aversion calls for research into how to specify the conditions bounding agreements and how to create incentives for research that stabilizes problem definitions (e.g., by aggressively looking for surprises). Active adaptive management approaches acknowledge ambiguity, by treating interventions as learning experiences (Shea et al., in press).

At times, proponents of precautionary principles want an analytical process that incorporates citizens and not just formal representations of their desires (through opinion polls, cost-benefit analyses, general elections results, etc.). As mentioned, there are increasing calls for such processes. For example, the U.S. National Research Council's (1996) deliberative-analytical process has citizens set the terms of risk analyses, which technical specialists then execute—keeping the citizens informed as

[12] There are a few notable exceptions, such as Sweden's national debate in the late 1970s, which stabilized moderate acceptance of the industry over the next two decades (Sahr, 1985).

they proceed. More research is needed regarding the success and conditions favoring such exercises. That research might involve case studies of natural experiments, experimental studies of alternative procedures, and the development of decision aids (e.g., for communicating uncertainty, summarizing degrees of consensus).

At times, precautionary principles are invoked to stop particular technologies. However, a general rule that achieved such specific goals may also stop otherwise acceptable technologies. Research might help to prevent such excesses, by partitioning technologies into analytically distinct categories, suited to common rules. For example, is there a reasoned basis for treating agricultural biotechnology based on genetic modification differently than that based on genomics, for identifying alleles that could then be selected through conventional breeding? Are there general rules for categorizing the objects of regulation, assuming no institutional constraints? (Fischhoff, 1983, 1984)

Of course, there are always constraints. As the technology emerged, GMOs were subsumed under existing regulatory structures, in a seemingly incomplete and incoherent way. If this is a common pattern for novel technologies, then better institutional design is needed, for commissioning, interpreting, and acting on analyses. Is there some way to retain regulatory flexibility, while a technology's contours become clear—without creating binding precedents or a dedicated bureaucracy? Are there recognizable triggers for systematic review, potentially reorganizing regulatory structures? Can one quantify the value of regulatory coherence, in making policy analysis more comprehensive, predictable, and competent?

Finally, the possible varieties of precautionary principle must be better characterized, preferably in ways conducive to realizing each better and identifying its domain of applicability. That domain is, likely, a function of the technology in question, the concerns it evokes, and the institutions implementing it. The potential value of closely reasoned precautionary principles is undermined by the co-existence of multiple vague ones. Reducing the number of competing principles may require their advocates to break ranks, lest the weak pull down the strong. Their deep, common concerns will not be served by unquestioning acceptance of one another's proposals, any more than it does for those in the industries being evaluated.

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