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Innovation, Insurability and Sustainable Development: Sharing Risk Management between Insurers and the State

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Both the public and the private sectors have responsibilities for managing the risks associated with new technologies. This article is about the interplay between three key concepts: the insurability of risk; innovation; and the broader framework of sustainable development. It is based on the recent EU INTEREST project[1] which addressed the role the insurance sector and insurance-based mechanisms might play in relation to innovation which promotes, or challenges, sustainable development. The project cast light on three issues: opportunities for promoting sustainable development through innovation by adjusting or sharing the responsibilities of private sector actors, regulators and policymakers; promoting sustainable development innovation by using risk management mechanisms from insurance in other domains or by the insurance sector using a wider set of tools to manage novel risks; and policy options for the complementary use of insurance-related and other risk management mechanisms.

The article begins by considering, at a general level, the interplay between insurability, innovation and sustainability, before moving on to consider five specific contemporary case studies: the development of GM crops; the risks associated with xenotransplantation; nuclear power; the tapping of freshwater submarine springs in the Mediterranean area; and the management of flood risks. The paper then draws out broader conclusions about the use of risk management mechanisms to promote sustainable development innovation. It concludes by considering implications for policymakers and insurers.

1. Introduction

Both the public and the private sectors have responsibilities for managing risks associated with new technologies. These responsibilities sit within the broader framework of sustainable development in which a balance is sought between economic, social and environmental goals, and in which the benefits of development are shared equitably among different social groups and across generations.

The insurance sector plays a key role in managing technological risk. By pooling risks, the insurance sector has for a long time facilitated the diffusion of new technologies in diverse fields including shipping, railways, pressure vessels and construction. Mandatory insurance requirements have helped to mitigate the negative consequences of technological innovation by forcing developers to take account of risk and liabilities in their decision-making.

The new frontiers of innovation, for example, in biotechnology, information and communication technologies, pose novel challenges for both the insurance sector and the state. At the same time, the pursuit of sustainable development highlights the need for

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[1] The full report was published in *Etudes & Dossiers*, No. 267, March 2003. This publication is available from The Geneva Association.

effective mechanisms to manage the risks associated with large-scale problems such as climate change. Technological innovation is the key to improving resource productivity, and is one of the keys to sustainable development.

This article is based on the recent INTEREST project[2] which addressed the role that the insurance sector and insurance-based mechanisms might play in relation to innovation which promotes, or challenges, sustainable development. The project consortium included representatives from academia, the insurance sector and the technology consultancy sector. The INTEREST project was based on two hypotheses: (a) that new technologies and sustainable development will together place new demands on the insurance sector; and (b) that the insurance sector and insurance-based mechanisms may have a greater role to play in managing the risks associated with innovation.

Among its objectives were to:

- identify opportunities for promoting sustainable development through innovation by adjusting or sharing the responsibilities of private sector actors, regulators and policy-makers;
- establish how sustainable development innovation can be promoted using risk management mechanisms from insurance in other domains;
- establish how sustainable development innovation can be promoted by the insurance sector using a wider set of tools to improve its capacity to manage novel risks; and
- explore policy options for the complementary use of insurance-related and other risk management mechanisms.

The article is about the interplay between three sets of issues: the insurability of risk; innovation; and sustainable development. It begins by considering the relevance of these three concepts, then moves on to describe how the two hypotheses above were tested using contemporary case studies. These are: the development of GM crops; the risks associated with xenotransplantation;[3] nuclear power; the tapping of freshwater submarine springs in the Mediterranean area; and the management of flood risks. The paper finishes by considering the degree to which the case studies have addressed the objectives set out above and draws out implications for policymakers and insurers.

2. The issues involved

2.1 The insurability of risk

The core business of insurance companies is to provide financial indemnity for losses arising from a defined set of causes. There are constraints on the types of risks that can be insured and on the magnitude of risks that can be transferred to insurance markets. Attempts have been made to formalize criteria for the insurability of risks. The most important are (Berliner, 1982):

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[2] INsurance, TEchnological Risk and Emerging Science and Technology policies. INTEREST was part of the EU STRATA Programme (STRATegic Analysis of specific political issues). The consortium included: the Policy Studies Institute (U.K.); Technopolis France; the International Association for the Study of Insurance Economics, (The Geneva Association, Switzerland); Gerling Sustainable Development GmbH (Germany); and the University of Linköping (Sweden).

[3] The transplantation into humans of organs from other species.

- the probability of events occurring;
- the *maximum* total loss associated with an event;
- the *average* total loss associated with an event;
- the average time span between two events;
- the level of insurance premium required;
- the degree to which insured parties can manipulate the risk (moral hazard);
- the degree to which parties subject to greater degrees of risk are more likely to seek insurance (adverse selection);
- legal limitations; and
- insurance cover limitations (liability limits, deductibles, etc.).

In general, low frequency/high severity events, such as nuclear power incidents, are not insurable, whereas high frequency/low severity events, such as motor accidents, represent ideal risks for insurers (Figure 1).

However, insurers take on specific risks in the light of practical experience and commercial considerations. The willingness and capacity of insurers to provide insurance, and therefore the boundary between insurable and uninsurable risks, is determined not only by formal insurability criteria but also by the socio-economic context in which insurers operate. Of particular importance are: regulatory and legal limitations; pricing issues; the demand for insurance in the marketplace; and the capacity of insurers to provide sufficient risk transfer.

2.2 Technological innovation

A number of insights from innovation studies are relevant to the insurability of risk and the role of the insurance sector.

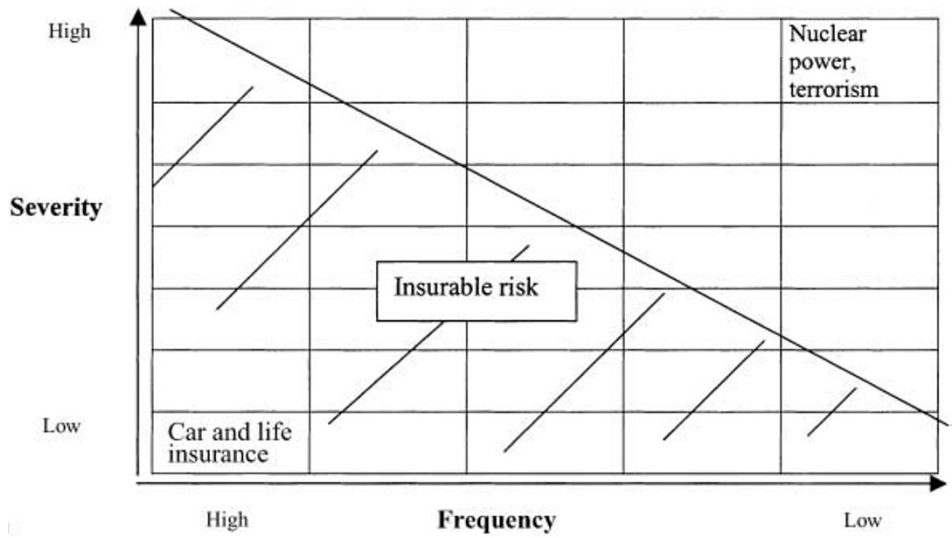

Figure 1: Insurability of risk

First, innovation is not a linear process from science to market, but an interactive process involving a multitude of actors, such as developers, users, financiers, and regulators (Von Hippel, 1988; Bjiker, 1992). Second, innovation is a socio-technological process. Technologies implicitly or explicitly define the social environment in which they are able to function. Technologies are shaped by collective social action, but simultaneously shape the politics, the users, and the infrastructure associated with them (Callon, 1987; Latour, 1992). Third, innovations are path-dependent, that is, they tend to become locked in to certain trajectories of development. This results in *technological paradigms* within which patterns of innovation become relatively fixed over long periods of time (Dosi, 1982; Nelson and Winter, 1982; Sahal, 1985). The establishment of the "QWERTY" keyboard as a standard in spite of the existence of superior configurations is often cited as an example of this tendency (David, 1986). Finally, innovation processes tend to be characterized by uncertainty rather than quantifiable risk (Callon, Lascoumes and Barthes, 2001).

Technological innovations are frequently portrayed as not being amenable to traditional insurance mechanisms due to the lack of actuarial data from which premiums can be calculated. The role of insurers is normally limited to the more "downstream" stages of innovation (demonstration, diffusion, adoption). In order to influence the social context in which innovation occurs, ahead of technological lock-in, insurers would need to obtain a better understanding of the relevant technologies and the effects of their deployment. One of the case studies described below shows that insurers *would* be prepared to consider the risks associated with events for which there is no prior experience, as long as there are credible methods for characterizing and quantifying risk.

2.3 Sustainable development

The EU Council of Ministers adopted a clear agenda for grappling with sustainable development issues in June 2001. The elements included: getting the prices right; investing in science and technology; and improving policy coherence. Each of these areas holds implications for the insurance sector.

If prices reflect social and environmental externalities, individuals and businesses have the incentive to change behaviour and invest in technologies, products and services that will fulfil social needs while reducing environmental pressures. One element of "getting the price right" is pricing risk appropriately. Here the insurance sector has an important role to play.

Investment in science and technology is essential so that sustainable development can be pursued by reducing use of natural resources, cutting pollution and mitigating risks to health and safety. The role of the state is to promote basic and applied research into sustainable technologies and to fund benchmarking and demonstration projects. The insurance sector could provide risk management mechanisms which will lower barriers to innovation.

Sustainable development depends on policy coherence. This means assessing the full economic, environmental and social impacts of every policy proposal. In taking account of impact assessments, policies must take account of the precautionary principle. Loss prevention activities associated with insurance could potentially enhance the precautionary approach. Under any unlimited third-party liability regime, the insurance sector would be required to price future risks, forcing innovators to internalize the costs, with the result that "unsustainable" technologies would be screened out.

Ewald has argued that there has been a long-term development of the insurance sector's approach to risk (Ewald, 2001). In the 19th century, insurance was greatly influenced by the pursuit of social security in the workplace. The 20th century was characterized by the

development of risk management based on risk minimization and loss prevention. Ewald argues that the 21st century will be characterized by use of the precautionary principle.

The key is how the state chooses to apply the precautionary principle, and the choice of liability regime. The European Commission links the precautionary principle with a structured approach to risk assessment, risk management and risk communication (European Commission, 2000). The precautionary principle needs to be invoked only where: (a) potential negative effects have been identified; and (b) scientific evaluation of the risk makes it impossible to determine with sufficient certainty the risk in question. The Commission also insists that, where the precautionary principle needs to be invoked, the appropriate responses are in the nature of political decisions. If the precautionary principle must be invoked, then the risk must by definition be uninsurable.

However, there are "stronger" interpretations of the precautionary principle that would allow a wider role for insurance. For example, the Commission identified a set of risks which fall below the uncertainty threshold required for the precautionary principle to apply. These are circumstances where no direct evidence is available about a risk but plausible inferences can be made. Such approaches are seen as being "prudential" in nature. Here, it may be possible to meet insurability criteria. Although there are potential links between precaution and insurance, the political nature of many emerging risks may constrain the use of insurance mechanisms.

3. Case studies in insurability

The key issues discussed in the previous section were tested in the course of the INTEREST project through five practical case studies. These were selected according to the following criteria:

- Did they cast light on innovation processes?
- Did they relate to the economic, social or environmental aspects of sustainable development?
- Did they raise insurability challenges?
- Did they cast light on the precautionary principle?
- Did they address new societal risks?
- Did they offer opportunities for replication?

Not all case studies met all of the criteria but, collectively, they covered the full range of issues. The selection was also made with regard to the sector involved, the type of innovation (radical, incremental) and the potential role of the state. Tables 1 and 2 map the case studies against the selection criteria and other factors.

From the selection, it was evident that insurance has distinct roles to play in relation to innovation and sustainability, including:

- regulating the rate and direction of innovation associated with radical technologies which have potential impacts on the environment or third parties and whose sustainability is contested (GM crops, xenotransplantation and nuclear power);
- underpinning the development and deployment of technologies which promote sustainability by managing technological risks (tapping submarine freshwater springs); and
- promoting innovative solutions for managing risks associated with natural hazards such as floods.

Table 1:
Case study criteria

Does the case study:	**GM crops**	**Xeno-transplantation**	**Nuclear power**	**Submarine freshwater springs**	**Management of flood risks**
Cast light on innovation processes?	√	√	√	√	~
Relate to sustainable development?					
– economic	√	√	√	√	√
– social		√	√		
– environmental	√		√		√
Raise insurability challenges?	√	√	√	√	√
Cast light on the precautionary principle?	√	√	√		√
Address new societal risks?	√	√			~
Offer opportunities for replication?				√	

Table 2:
Case study coverage

Does the case relate to:	**GM crops**	**Xeno-transplantation**	**Nuclear power**	**Submarine freshwater springs**	**Management of flood risks**
The potential role of the state?	Regulatory, research, communication	Regulatory, communication, research	Regulatory, legal framework, R&D, funding	Minimal	Legislation, insurer of last resort, loss prevention
Specific sectors?	Agriculture, biotech	Healthcare	Energy	Manufacturing	Household and other
The type of innovation?	Radical	Radical	Problem-solving	Take-up of near-market/existing technology	Infrastructure, systems

A common analytical framework was used, modified as necessary to take account of the specificities of individual case studies. The framework covered:

- characterization of the issue (technological state-of the-art, legislative framework, current role of insurance and public risk perceptions);
- risk management and the role of different risk management actors (e.g., the state, insurers); and
- implications for innovation, sustainability and insurability.

The case studies were developed by experts in the relevant fields, not necessarily with formal expertise in insurance matters. In a workshop environment, the case studies were presented and commented on by insurance experts. The case studies were then refined building on the expertise of both subject experts and insurers.

4. Liability, insurance and contested technologies

4.1 Genetically modified crops

Since the 1990s, genetically modified (GM) crops have been cultivated in the open environment for both research and commercial purposes. GM crops could result in plants with improved traits for food production (such as herbicide-tolerant soy) and for non-food products (biodegradable plastic or timber). The rapid development of GM has led to wide debate about the risks versus benefits of GM crops. In Europe, widespread controversy in the 1990s led to a moratorium on the commercial cultivation of GM crops. Issues relevant to insurance, such as risk assessment and environmental liability, have been central to this debate.

There are specific environmental risks associated with the deliberate release of GM crops. These include the unintentional breeding of a GM crop with a related wild plant, creating a new kind of weed and the unintended transfer of modified genetic material from the GM crop to other species (horizontal gene transfer). For insurers, this creates a product liability problem. Traits can be transferred from one generation to another (vertical gene transfer). So-called "terminator" GM crops, modified to be infertile, are favoured by the industry but have met public opposition. "Terminator" technology would however reduce the scope of the risks faced by insurers. The widespread use of insect-resistant crops will eventually lead to insects becoming resistant to the toxin contained in the GM crops. Similarly, wild plants may develop resistance to herbicides used in GM crop cultivation. GM crops may contain chemical substances that distinguish them from their non-GM parent plant, creating a risk of harmful effects on non-target organisms.

There are potential risks to animal welfare and human health. There is a theoretical risk that the consumption of GM plants might induce unwanted antibiotic resistance in cattle. Theoretically, there is a risk of antibiotic resistance being transferred to humans from GM food or indirectly via animals. GM crops might also provoke allergic reactions in humans.

There are financial risks associated with indirect losses sustained by third parties. GM contamination may affect conventional and organic crop growers. There have been several recent cases where developers, insurance companies and the state have denied liability in connection with impacts on non-GM crops.

From the developer's perspective, public perceptions of the above risks, as well as the lack of consumer choice, constitute a special class of risk termed "social risks". "Social risks" point to the inherent cognitive, normative and practical uncertainties associated with

GM crop technology. Managing social risks means going beyond traditional scientific risk assessment.

Current European regulation of the deliberate release of GM crops does not include civil liability or insurance for environmental and social harm. These difficult issues are being addressed in the context of the negotiations on the draft Environmental Liability Directive (European Commission, 2002) (see below).

In general, the lack of actuarial information to assess the probability and scale of adverse events, the possibility of low probability, large-scale events and the socially sensitive nature of GM technology pose challenges for insurers:

- unknown potential environmental, health and social hazards involved in GM crop technology make it difficult to quantify potential environmental damage;
- it is difficult to prove damage given the complexity of the technology and its interaction with the environment; and
- responsibility is difficult to assign. For example, if a GM tomato is found to be harmful, is the developer, the farmer, the retailer or the restaurant liable?

There is also a political risk in that the state may change the rules after the risk has been priced, rendering limitations on cover unclear.

It can be argued that the absence of a strict liability regime has facilitated the introduction of GM crops into the European market. Furthermore, the protection offered to developers by the GMO Deliberate Release Directive and the Novel Food Regulation has essentially shifted much of the potential risk from any unexpected hazards arising from these products on to the state. Nevertheless novel liability problems associated with the GM contamination of non-GM crops have recently begun to emerge.

The proposed Directive on Environmental Liability would change the regime, and has already drawn the insurance sector into political debate. The draft Directive is based on the principle that polluters should pay for the damage they cause to the environment, or for measures to prevent the imminent threat of such damage. As originally proposed by the Commission, the regime would be founded on strict liability in respect of land, water and biodiversity damage from "dangerous activities" regulated by specified EU legislation, including the contained use or deliberate release of GMOs. However, there would be exemptions for damage by activities not considered harmful at the time (state-of-the-art defence), or allowed by law or by an operator's permit (permit defence). These defences would not apply if the operator had been negligent.

In addition, the Directive, as originally proposed, "would not give private parties a right of compensation for any economic loss sustained in consequence of environmental damage or of an imminent threat of such a damage". This is critical for GM crops, because of the possibility of economic damage sustained by conventional or organic farmers. Environmental NGOs have argued that traditional damage should be brought within the scope of the Directive.

Member States would be required to encourage operators to use insurance or other forms of financial security and to encourage development of such arrangements although no compulsory scheme is proposed. However, according to the European Federation of Insurance Associations (CEA), the draft Directive defines biodiversity in too broad a way and biodiversity damage "cannot be considered currently insurable" (*Environment Daily*, 2002). The CEA expressed similar concerns about insurability should the currently proposed exemptions relating to permit and state-of-the-art defences be deleted from the final draft of the Directive. The political debate over the draft Directive has yet to be resolved.

It is only possible to speculate as to how much the liability regime has affected the development of GM technology. However, it is reasonably certain that insurers would have been unwilling to underwrite the currently unquantifiable risks associated with the introduction of GM if strict liability had been required. There are limits to insurance-based approaches to developing and regulating GM crops, because the risks and benefits involved are of a wide societal nature.

4.2 Xenotransplantation

This case study explored issues raised by the proposed use of genetically engineered (GM) pigs as organ donors for cross-species (or xeno-) transplants to human patients. Over the last 40 years, human-to-human organ transplants have significantly prolonged the lives of many hundreds of thousands of people worldwide. However, as transplants have become increasingly routine, the demand for treatment has significantly outstripped the supply of donor organs.

Advances in biotechnology appear to offer a solution to this problem. Xenotransplantation is more difficult to achieve successfully than human-to-human transplants. The best understood barrier to xenotransplantation is hyper-acute rejection, in which the immune system recognizes a transplanted animal organ as non-human and destroys the organ within a matter of minutes or hours. By genetically engineering pigs to make their organs human-compatible it is hoped to provide an almost limitless supply of spare parts for transplant surgery. The technology entails significant and currently unquantifiable public health risks as well as raising ethical concerns about the treatment and use of animals.

In 1997 researchers showed that porcine endogenous retroviruses (PERVs) could infect human cells in culture. What effect they would have if they were to infect a living human patient is unknown. This research therefore focused international attention on the risk that xenotransplants from GM pigs could introduce potentially devastating new diseases into the human population.

There are several safety risks associated with xenotransplantation. For the patient, there are risks that the donor GM pig organ will not function as effectively as a human organ, that it will be rejected, or that they will contract a xeno-related disease. Family members or close contacts of the patient are also at risk. Medical staff or those involved in the breeding, transportation and sacrifice of the source animals could contract a xeno-related disease. There is also a risk that a xeno-related disease will be transmitted into the wider population.

There are also economic risks. There could be financial losses to the developers if the technology cannot be made to work or cannot be brought to the "market" due to the safety or other concerns. There could be public or private sector liability to pay compensation to those infected or their families should xenotransplantation lead to the introduction of a novel disease. There could be additional costs to the health care system for screening and treating anyone who contracted a xeno-related disease.

Social and ethical risks include the loss of trust and political legitimacy if regulation does not take into account public concerns and the civil liberties implications of dealing with the introduction of a xeno-related disease into the human population.

Unlike the case of GM crops, liability and insurability issues have not so far featured prominently in public debates over the acceptability of xenotransplantation. This may simply be because the technology has yet to enter clinical trials, and hence such concerns have not yet come to the fore. However, it may also reflect a lack of foresight on the part of official regulatory and advisory bodies.

For example, the clause on "financial and insurance" aspects in the UKXIRA application form for a licence to carry out clinical xenotransplantation trials in the U.K. takes no account of the particular risks to third parties inherent in the technology.[4] Hence, there is currently no requirement for applicants to obtain insurance cover against risks to third parties. Given the degree of novelty and uncertainty that characterize these risks, and the potential magnitude of the worst-case scenario associated with the "escape" of a potentially fatal infectious agent, it is in any case unlikely that the insurance sector would be willing to provide such cover. The likely absence of insurance cover could be construed as an indication, or financial "signal", that alternative ways of dealing with the organ "gap" should continue to be pursued.

One response to the complex risk management and regulatory challenges posed by xenotransplantation has been to turn to the emerging field of participatory technology assessment ("PTA"). Such techniques are particularly useful where there is insufficient knowledge or certainty to undertake or have confidence in conventional quantitative risk assessments, and where technological developments entail wide-ranging social, ethical and political risks. Both Switzerland[5] and Canada[6] have recently undertaken major exercises of this kind, whilst in the U.K. the Wellcome Trust is sponsoring the Deliberative Mapping project[7] looking at xenotransplantation and end-stage kidney failure.

The main conclusion to be drawn from this case study is that, in the case of controversial and contested technologies, the non-availability of insurance cover may encourage a more precautionary approach and the reliance upon, or the development of, safer alternatives.

A second conclusion is that techniques such as PTA could assist policymakers and society more generally in the exploration and evaluation of novel risks and uncertainties. The scope for the insurance sector to employ such techniques is likely to be limited, as it may not be in a position to insure the risks associated with xenotransplantation. However, the sector could contribute to public debate on innovation and sustainable development by participating in such assessments.

4.3 Nuclear power

Today, 430 nuclear reactors generate electricity for civil use. The industry is highly regulated and is characterized by international co-operation on harmonization and standardisation. The whole lifecycle for nuclear power needs be considered, from the "front end" cycle, through power plant operation, to the "back end cycle" of waste disposal. Nuclear power is also a good example of irreversibility: once the technological choice has been made and the infrastructure built, it is extremely difficult to reverse the decision.

Like other industrial activities, the nuclear industry addresses the typical risks of fire, machinery breakdown, human error, property damage, liability and business interruption losses. But the specific risk induced by the nuclear power industry is the release, through both accidents and low-level continuous releases, of radioactive elements that may harm humans

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[4] Profoma for use by applicants to the UKXIRA, reproduced as Annex 4 UKXIRA Third Annual Report, see: *http://www.doh.gov.uk/ukxira/ukxann3.htm*

[5] Center for Technology Assessment (2000), Federal Office of Public Health, Swiss National Science Foundation (2001), "*Transplant Medicine, 24-27 November 2000 at Bern: Citizen Panel Report*", TA - P 2/2000 e.

[6] *http://www.xeno.cpha.ca/english/finalrep/reporte.pdf*

[7] *http://www.deliberative-mapping.org/*

and the environment over their lifetime. The probability of a nuclear accident is very low, but the damages incurred could be extremely high. The challenges are non-actuarial risk assessment, risk management with a particular focus on safety, and the capacity to handle damages. Currently, the biggest challenge is financial capacity rather than technical or technological risk assessment and management.

Civil nuclear incidents are classified according to the scheme in Table 3. The cause of nuclear accidents is often social or managerial, as in the case of both the Chernobyl and Three Mile Island accidents.

The operator of a nuclear installation is exclusively liable for accidents at, and in relation to, that installation, including transport of nuclear substances. This "channelling" of liability on to the operator simplifies and therefore expedites actions for damages brought by victims. It also minimizes the burden upon the nuclear industry as a whole, as the various persons who contribute to the operation of a nuclear installation, such as suppliers and carriers, do not require insurance coverage additional to that held by the operator.

Liability is "absolute". Under the Paris and Vienna Conventions, the operator of a nuclear installation is liable, regardless of whether fault or negligence can be established. This greatly simplifies actions for damages, as the nuclear field is so complex that fault could be very difficult to prove.

Under the Paris Convention, the maximum liability of an operator is U.S.$ 21 million. However, a party to the Convention may take into account the possibilities of obtaining insurance or other financial security and establish a greater or lesser amount by legislation, to a minimum of U.S.$ 7 million. The OECD Steering Committee for Nuclear Energy has recommended that Contracting Parties to the Paris Convention aim at setting the maximum liability at not less than U.S.$ 210 million. Under the Vienna Convention, the liability of an operator may be limited to not less than U.S.$ 5 million.

Direct insurance coverage exists in the field of compulsory liability, decontamination and decommissioning of property, and business interruption. As liability insurance is compulsory, the other policies may be optional. Historical analysis seems to reveal that the largest insurance risk involves main turbines, main generators, reactors and internals, transformers and pumps. Reinsurance is provided by 25 national insurance pools worldwide as well as by mutualities.

Nuclear liability limitations are not very different from other existing liabilities, e.g., for transport. As a result of the lack of actuarial data, pricing is subjective for catastrophic risks. However, the pricing of lower level risks is increasingly influenced by an actuarial approach. Prices are likely to approach realistic risk prices, thanks to continuous improvements in technological risk assessment.

Table 3:
Classification of nuclear incidents

1	Major accident (e.g., Chernobyl, USSR, 1986)
2	Important accident
3	Accident presenting an external risk (Windscale, U.K., 1957; Three Mile Island, U.S. 1979)
4	Accident inside the installation (Saint-Laurent, France, 1980)
5	Problem affecting security (Vandelos, Spain, 1989)
6	Problem causing secondary development
7	Malfunction

This case study raises two major issues:

- whether nuclear power can be characterized as sustainable; and
- the role of the insurance sector and, especially, what might have happened had the insurance sector been engaged earlier in the decision-making process around nuclear waste.

On the one hand, nuclear power can be said to promote sustainable development by contributing to reductions in greenhouse gas emissions. On the other hand, it challenges sustainability through the problems of waste disposal and the risks of nuclear accidents. Whatever the balance of argument, it is clear that social attitudes to the sorts of risks posed by nuclear power – low probability but with potentially very significant short- and long-term consequences for whole societies – have changed in the last half-century. There have been radical changes in risk perception in societies, with a decreasing acceptability of collective intergenerational risks, of which nuclear power is a good example. The events of 11 September have highlighted the need to consider societal vulnerabilities, which impact on the sorts of collective knowledge, information and technology needed for future generations to manage the risks we have created. Nuclear power may well be a relatively vulnerable technology in this respect.

It has already been suggested that the insurance industry may need to become involved at an earlier stage in the innovation process. The nuclear power case study highlights reluctance on the part of insurers to do so. Insurance companies are motivated by short-term profit and have few resources for involvement in activities that might bring benefits only in the long term.

It depends also on the nature of the technology. Insurers might be reluctant to get involved with new technologies whose applications could complicate identification and definition of the "triple trigger" for insurable events. This trigger, determining when an event happened, what caused it, and when the damage was discovered, is important for establishing which insurance policies, if any, are applicable. With nuclear power, and many other reasonably new technologies, it is often difficult to even define an "event". There is too much scientific uncertainty and dispute as to which level of radioactive release would qualify as a damage event.

5. Insurance mechanisms and sustainable innovation

5.1 The Nymphea Water project

The Nymphea Water project attempts to tap water resources from submarine freshwater springs. The project relates to sustainable development in different ways, as it is thought that it will have a major positive impact on local economies and social contexts while mitigating the adverse environmental impacts associated with water scarcity.

Nymphea Water is a subsidiary of GEOCEAN, a specialist in offshore operations, and was created in 2000 to exploit submarine freshwater springs through the construction of "sea domes" to extract the freshwater. While the phenomenon of submarine freshwater has been known since antiquity, few attempts have been made to tap this resource. It is a research and development project: industrial implementation will only take place once exploration and construction have been completed. About 42 countries, mostly around the Mediterranean, have been deemed favourable for commercial investigation as they have potential sub-sea springs and regularly suffer freshwater scarcity.

The project raises a number of insurability challenges. As with all innovation, the lack of historical data and feedback impede the traditional actuarial approach of insurance, to the detriment of the innovation process. The possible underperformance of a new technology entails financial consequences that could affect the business plan, endanger third-party involvement and undermine the entire development.

In order to insure this kind of project, the traditional actuarial approach needs to be replaced by a factual approach, based on industrial and scientific risk assessment. New insurance products, underwriting behaviour, and risk management tools need to be employed.

A "Technological Performance Achievement" ("TPA") is a new form of cover suggested for application to technological innovations. The scope of the TPA was tested in the French robotic sector market between 1993 and 1995 on about ten innovative processes developed by the French company GAN. Underwriting was based on confidence in the reputation, know-how and reliability of the insured party.

The method employed to develop such a cover is a bottom-up analysis to investigate typical failure paths of all the components of a system. Three tables were used in the Nymphea Water study: a "gravity" table; a probability table; and a criticality table.

The gravity table indicated the level of seriousness of any identified failure consequences. The probability table defined the likelihood of investigated failures. Rather than using exact probabilities, these were divided into banded classifications covering the range of probabilities. The criticality table combined the probabilities with their gravity, to provide a risk estimation of the different consequences.

Identifying the consequences of different failures and their probabilities helped assess the financial and overall impact on the project as a whole from different failures, and resulted in a set of recommendations enabling improvements and refinements in its design.

This scientific risk assessment can serve as a basis from which small and medium enterprises ("SMEs") can set up relevant integrated risk management procedures to run projects and prevent involuntary failure. Underwriting technological performance achievement not only provides coverage but also addresses the crucial need for SMEs to demonstrate their credibility and solvency when scrutinized by clients, banks, financiers, and, possibly, state innovation agencies.

This case study demonstrates that innovative processes can be further enhanced by expanding the role of the insurance sector, particularly through support for smaller companies. Not only is the financial assurance vital for many SMEs, but the involvement of the insurers can facilitate innovation before it reaches the market and improve general risk management practices.

However, in order to more actively promote innovation, the insurance sector needs to use a wider set of risk assessment and management tools, as an actuarial approach is not applicable. This hinges to a great extent on the skills and competences of individual insurance companies, and also on the general willingness of the sector to expand business opportunities in this direction. This case study also highlights the challenges of engaging early in the innovation process and forming collaborative arrangements with other stakeholders.

6. Innovative responses to natural hazards

6.1 Flood risks

Flood risks, and other phenomena traditionally referred to as natural hazards, make interesting case studies, as responses to them, and responsibilities for them, vary significantly

between countries. This case study was based primarily on the experience of Sweden supplemented by input on recent practice and experience in the U.K.

Global property losses from natural disasters increased tenfold in constant values between the 1950s and the 1990s. This is attributable to greater *per capita* ownership of assets, more coastal and floodplain developments, and a growing "compensation culture". Climate change may also be exacerbating damage caused by weather events.

Both the public and private sectors deal with flood risks, in precautionary as well as remedial modes, although the majority of precautionary measures are undertaken by the state. Examples of precautionary measures are: the establishment of rules; institutions; early investment in studies or research on causalities in general as well as local or regional historical impacts; and regulating responsibilities in case of a disaster. Measures to establish and finance weather impact warning procedures and general infrastructure investments are also precautionary measures. Remedial measures are both private and public, and concern responses to situations in which damage has already occurred, such as insurance payments or other forms of financial support.

In Sweden, precipitation is rarely extreme in character, but there are severe disturbances from time to time and considerable variations on a yearly basis. The last 15 years have been remarkable because of an unusually high frequency of weather-related disaster events. The year 2000 featured the highest ever recorded precipitation levels, with some major floods. However, rainfall is not the only element causing floods; another important contributing factor has been the release of water held in dams or reservoirs built by hydropower companies. This raises important questions of liability that are currently being debated in the Swedish parliament as well as at E.U. level with the draft Directive on Environmental Liability.

Sweden is characterized by a strong planning tradition. The idea that the state should cover losses due to large environmental accidents or hazards such as flooding is well established. The state also provides much information on flood risks, including detailed flood maps. On the other hand, the Swedish system is also characterized by a tradition of strong private insurance companies. However, floods are not viewed as a critical hazard for the insurance industry. Even in the exceptional floods of 2000, the total amount of insurance claims came to just around U.S.$ 20 million.

Household policies include cover for flood as part of a package of risks. However, flood claims are subject to a large deductible of 10 per cent of the amount of the claim, with a minimum of 10,000 Swedish kronor (about U.S.$ 1,000), and there is a maximum limit on indemnity of 100,000 kronor (about U.S.$ 10,000) in respect of the collapse of dams. Industrial policies may cover flood, dependent on the individual circumstances, but here the collapse of dams is completely excluded (Axco, 2001).

Precipitation patterns in the U.K. are not dissimilar to those in Sweden, but responsibilities for risk management are very different. The U.K. approach to flood risk relies heavily on the insurance sector. As a result of government pressure, U.K. insurers agreed in 1961 to give virtually universal flood cover, and the risk is incorporated into a package of risks to property, with minimal variations in premium rates. The system applies to domestic policies and small businesses; large businesses are dealt with on an individual basis to reflect their unique risks.

The exploration of flood risks sheds some light on the opportunity to promote sustainable development through innovative responsibility-sharing arrangements between the private sector and the state. In order to get the maximum benefit from a proactive insurance stance, there needs to be interaction with policymakers and a willingness to participate in an

interdisciplinary process, in which financial concerns are blended with a range of other considerations like public safety, amenity and economic development.

Apart from the industry-wide position, individual insurers must develop their own individual strategies. For most, this means being more selective in the risks they accept, and formulating new contractual terms for the insurance policies that they issue. A key factor is improving the quality of information about the level of risk of individual properties. Creating better databases is costly. So far only a very few companies have attempted it, and they are not likely to share their expensive tools with other insurers or stakeholders. Creating a geographical information system ("GIS") with accurate heights and property data is only the first step however. This has to be combined with models that simulate floods in order to gauge the potential costs, both for individual locations and in aggregate. These "black box" techniques do not inspire confidence in the user community, because currently there are wide differences in the estimates that they yield for flood exposure.

This tension between the roles of the private and public sectors in the provision of risk-relevant information will vary from country to country, reflecting a variety of factors, e.g., the magnitude of the hazard and extent of the private sector role in risk transfer.

Given that flood risks will increase with climate change, progressive insurers are adopting a far-reaching plan of action. They are seeking to identify the key hazards in more detail, through research and data collection. They are endeavouring to raise awareness in other stakeholders, in particular public authorities, and to work with them to manage weather hazards like flood, and to provide essential cover and recovery services, by refining existing processes, or innovation. Where they deem that the risk is too great to carry themselves, they can still provide administrative services in order to deliver an efficient risk management system, as happens with the National Flood Insurance Program in the U.S.

By improving their environmental management internally, and by ensuring that their investments support climate-friendly activity, insurance companies can also play a part in slowing the process of climate change.

7. Conclusions

The case studies have cast useful light on the basic objectives of the INTEREST project. However, the specificities of individual case studies have a great bearing on the conclusions. For example, the INTEREST project was conducted in an exclusively European context. Risk perception and sustainable development as issues are influenced by legal, political and economic culture, which may be interpreted differently in other parts of the world.

7.1 Sharing private/public sector responsibilities

The issue of shared responsibility between the private sector (insurance companies) and the state permeated most of the case studies. The state has a key role to play in defining the role which insurance plays in managing risk through the underlying legislative/regulatory framework.

The sharing of private/public sector responsibilities is a particularly difficult and sensitive issue when the sustainability of a novel technology is contested. The state may wish the insurance industry to take on certain risks, while the industry believes the risks to be beyond the frontiers of insurability. The INTEREST project has not generated universal prescriptions for policymakers, but it has suggested: (a) means by which policymakers can identify the circumstances in which insurance-related mechanisms might be considered; and

(b) pointers as to how insurance-related measures, and associated policy mechanisms, might be used to pursue policy goals.

The precise nature of any liability regime is critical. Broadly speaking, limited liability and restrictions that exclude liability if technology developers followed applicable regulations and operate on the basis of the best available scientific knowledge[8] will increase the likelihood that risks are insurable. At other times, the state may wish the insurance sector to step back as with the management of flood risks in The Netherlands. The role of insurance may need to be limited, and the compensatory role of the state increased, if a high priority is attached to social equity. The insurance sector prices risks according to the probability of the insured events occurring and the magnitude of the associated losses. This may place insurance beyond the reach of lower income households. Socially equitable compensation packages may need to be put in place, but loss prevention activities will fall below the economically efficient level as a result.

Specifically, policy options are available to the state that could:

- encourage precautionary patterns of behaviour on the part of technology developers, for example, by creating a strict liability regime;
- encourage responsible behaviour on the part of technology developers within the constraints of existing law and current scientific knowledge, by creating fault-based liability regimes;
- encourage innovation by creating regimes without liability and effectively assigning risk to third parties;
- encourage insurance companies into the "risk market" by placing limits on liability; or
- promote social equity by making insurance mandatory to protect third parties against loss.

These goals cannot be pursued simultaneously. Ultimately, the role that the state assigns to the insurance industry depends on higher-level political considerations, taking into account not only the level of risk but also its distribution across different groups in society.

7.2 Wider use of insurance mechanisms

The project has provided some insight into the wider use of insurance mechanisms, such as loss prevention. The state is already involved in loss prevention activity particularly in relation to natural hazards such as earthquakes or flood risks. The state could learn from the insurance sector by adopting a more systematic approach to policy integration. The flooding case study demonstrated how risks could be managed by co-ordinating land-use planning, flood prevention investments, liability regimes and public compensation schemes for vulnerable householders. The formulation of such policies can have an intensely political character and will be influenced by cultural perspectives on goals such as economic efficiency and social equity.

The submarine freshwater springs case study showed how insurance could underpin innovation by covering associated technological risks. Largely, this type of activity could be followed up by the insurance sector without state involvement. However, if the state is already promoting sustainable technology by using support mechanisms and information/awareness campaigns to overcome " access to capital" and information barriers to technology adoption,

[8] The so-called "permit" and "state-of-the-art" defences in the draft E.U. Environmental Liability Directive.

the insurance sector could play a complementary role by helping to overcome risk-related barriers to technology adoption.

7.3 Using a wider set of tools in the insurance sector

The project has identified considerable scope, at least at the theoretical level, for the insurance sector to use a wider range of tools for assessing and managing risk, thus expanding the boundaries of insurability. However, the immediate prospects appear to be more limited. For example, the disconnection between the investment and underwriting activities of the industry is in itself a potential barrier to further action. Any significant expansion in the boundaries of insurability would need to be underpinned by three developments.

First, there needs to be a greater interest on the part of the sector in the *upstream* stages of the innovation process. Currently, the sector engages only when innovation has reached the demonstration/diffusion stage and patterns of technological innovation have become "locked in". By getting involved earlier, insurers would be better placed to understand the risks associated with novel technologies. More speculatively, if they were prepared to influence the development of technologies before "lock in" occurred, they could prevent future losses and increase the likelihood that associated risks would be insurable. The relevant tools include risk and technology assessment tools traditionally used in the public sector. As the GM case study demonstrates, technological risks associated with innovation are often amplified by public perceptions. This could in itself affect the insurability of technological risks. Tools such as "participatory technology assessment" could help the insurance sector gain a better understanding of risk amplification and its impact on insurability.

Second, the sector would need to acquire a greater understanding of the technologies it insures, either through recruiting qualified staff or through procuring suitable technical consultancy services. The submarine freshwater springs case study showed how a more detailed technical understanding could allow technological (but not entrepreneurial) risks to be covered in ways that have not been previously possible. The engagement of the insurance sector could promote the development and uptake of sustainable innovation, by helping to manage technological risks and providing developers with a more secure financial framework. Insurers would need to use a wider set of tools, such as the "fault tree" analysis used in the Nymphea project, which allows risks to be assessed *ex ante* as opposed to *ex post* through actuarial methods.

Finally, collaboration between the insurance sector and other stakeholders would need to be stepped up. Possible actions include: the wider adoption of the corporate social responsibility agenda; participation in sustainable development fora; and participation in technology foresight activities.

The second and third types of development are perhaps easier to foresee than the first. Gaining technical expertise and increasing collaboration would be a considerable step forward for many insurers, but the sector need not move beyond its traditional interest in the diffusion and application of technologies. Moving upstream in the innovation process would require a more profound cultural change.

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