4. Managing environmental risk through insurance

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Risk is inherent in all human activities, both personal and professional. While the number and variety of risks have grown and changed dramatically throughout history, the basics remain the same: risk of loss of life, limb, health, livelihood, or property due to predictable events (reduced income upon reaching the mandatory retirement age) or to unpredictable events (loss of life in an earthquake).

There are some risks that governments, corporations and individuals choose to retain, consenting to pay for any losses that result from those risks. There are many more risks that exposed parties would prefer not to retain. Insurance can often be used as a policy tool to transfer these risks to another party. It has the added advantage that it can encourage the entity through premium reductions to invest in cost-effective risk reduction measures.

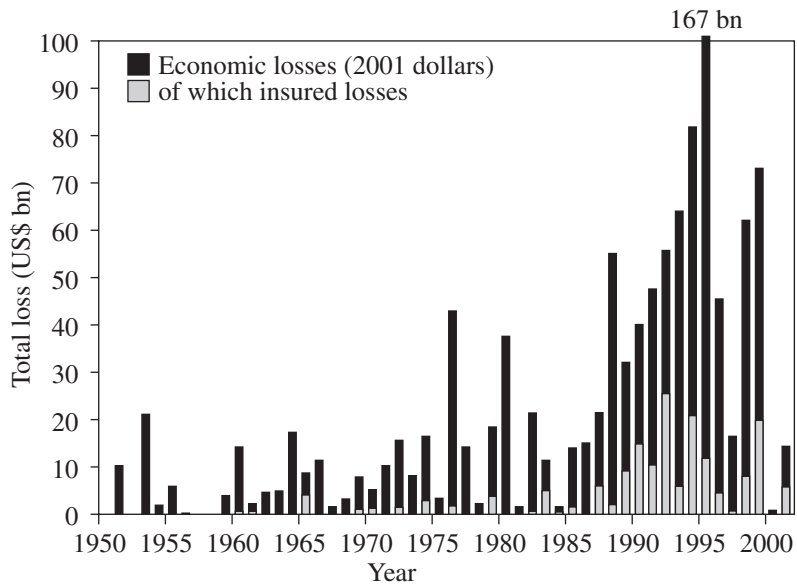
Increasingly, policy-makers have been exploring the proactive use of insurance as a tool to manage environmental risk effectively. In particular, five attributes of insurance exist that make it an effective risk management tool: its ability to spread risk; its role in variance reduction; its ability to segregate risk; its encouragement of loss reduction measures; and its ability to monitor and control behavior. The precondition for utilizing insurance as a policy tool is that the risk in question must meet a set of preconditions that make it insurable.

This chapter explores the role that insurance can play in managing environmental risk. We define environmental risk rather broadly to include natural hazards as well as technological risks. Section 1 explores the nature of environmental risk and the role that the public sector and private insurance can play in managing it. Section 2 then discusses the conditions that make a risk insurable. Section 3 focuses on two examples using insurance to address environmental problems: the role it can play as part of a national strategy for coping with natural hazards and how it can be used in conjunction with third-party inspections to enforce government regulations. The chapter concludes by discussing both the strengths and limitations of insurance as well as suggesting directions for future research.

1. MANAGING ENVIRONMENTAL RISK

Environmental risks are particularly challenging because they are normally low-probability events that can produce severe consequences. Natural hazards, such as earthquakes and hurricanes, can cause mass destruction and take many lives; technological risks, such as chemical accidents, can adversely impact the environment and cause human health problems.

With respect to natural hazards, Figure 4.1 depicts the losses due to *great natural catastrophes* from 1950 to 2001 throughout the world.[1] The Figure includes data on the overall economic and insured losses worldwide (in 2001 dollars) from earthquakes, floods, windstorms, volcanic eruptions, droughts, heat waves, freezes and cold waves.[2]



Source: Munich Re (2002).

Figure 4.1 Losses due to great natural catastrophes worldwide

A few interesting points emerge from the graph. First, there is an upward trend in both economic losses and insured losses worldwide over the course of these 50 years. This trend will likely continue into the future due to the higher concentration of population and built environment in areas susceptible to natural hazards worldwide. Next, a jump in both the economic losses and the insured losses took place within the last decade of the

century. Since 1990, worldwide losses were over $40 billion each year with few exceptions. Losses were as high as $167 billion in 1995 alone. As a result of an increase in the insured property value, the insured losses also grew during this same timeframe (Grossi and Kunreuther, in press).

Despite the concentration of capital assets in the developed world compared to emerging economies, the economic impacts of catastrophes are relatively evenly split between these two groups of countries. The developed world primarily bears the costs of windstorms (hurricanes and tsunamis) while the developing world bears the brunt of economic damage from flooding. The cost of earthquakes tends to be equally divided between the developed and developing world (Freeman, 2000). However, based on the enormous disparity in the gross domestic product between the two, the per capita impact of natural disasters in the developing world is dramatically higher. According to the World Bank, the impact in the developing world is 20 times greater on a per capita basis (Gilbert and Kreimer, 1999).

The financial implications of environmental damage from commercial activity are also enormous. The accrued liability for environmental risk related to real property in the USA alone is estimated at $2 trillion, or approximately 20 per cent of the total value of all property in the country (Wilson, 1991). This environmental liability primarily arises from the imposition of standards of care arising from governmental regulation. Since the 1960s, the USA and Europe have seen the creation of hundreds of federal, state and local statutes that assign liability for the contamination of air, water and soil resources.

Role of the Public Sector

When the federal government is the entity that absorbs a particular risk, there is the implicit assumption that this type of disaster is the responsibility of all residents in the country. The government has the ability to transfer these risks to each citizen through the power of taxation (Arrow, 1992). If the number of taxpayers is large, and/or the cost of the risk is small relative to the economy, the risk faced by each taxpayer is likely to be sufficiently small that it will not be of concern to citizens.

The government assumption of risk creates an enormous incentive for policy makers to design public sector programs. In dealing with natura hazards, there are abundant examples of governments assuming a portion of the risk of others. The creation of a government-subsidized insurance scheme is the most common example. The natural hazard programs in France and Spain and the National Flood Insurance Program (NFIP) in the USA illustrate these approaches (Pollner, 2000).

The creation of the Turkish Catastrophe Insurance Pool (TCIP) in 2000

is an example of a new program developed in an emerging economy. Under the TCIP, all existing and future privately owned property is required to contribute to the TCIP. The payments made will contribute to a fund that will pay homeowners up to $28 000 in the event that a catastrophe damages their homes (Gulkan, 2001). Proposals are now being explored in Mexico, the Caribbean, Central America and Africa to engage the government in providing risk-transfer options for farmers, homeowners and businesses in case of natural-catastrophe losses (World Bank, 2000).

All of these proposals are balancing the appropriate role of the government in emerging and developing countries to assist in the creation of market mechanisms to manage risk from natural hazards more efficiently. These proposals build on the active role played by the World Bank in helping Turkey establish the TCIP.

In the USA, government benefit programs have also been created to absorb risk from environmental contamination. State Guarantee Funds were established by states to absorb liability placed on property owners due to the enactment of new regulations governing underground storage tanks. In these programs, taxes are collected on the sale of gasoline to create a fund to pay for the cleanup of contamination caused by leaking tanks. To the extent that the fund is inadequate, other tax sources are used to supplement the required funds (Boyd and Kunreuther, 1997).

There are disadvantages to relying on government-assisted programs to cope with risk. Government programs generally treat all disaster victims identically without regard to their need for benefits or their ability to pay. The question normally asked before providing disaster relief benefits is whether the claimant resided within the designated disaster area, not whether the claimant should have avoided living or working in that region in the first place (Priest, 1996). For example, federal government benefits to those damaged by wildfires is dependent on whether the claimant lived in the fire zone. The fact that the claimant made a deliberate decision to expose himself to damage by consciously living in a high-risk zone does not impact his ability to receive assistance after the disaster.

Transferring risk to the government implies that citizens are willing to have the risk borne by them through some form of taxation. For most developing countries, the losses associated with some catastrophic natural disasters are beyond their ability to absorb these costs (Ferranti *et al.*, 2000). A graphic example is Hurricane Mitch, which caused direct and indirect damages in Honduras equivalent to $6 billion, or one year's gross domestic product. With a population of 6.2 million and 53 percent of the population below the poverty line, the cost of $1000 per person is beyond the ability of the government to absorb by relying on taxation.

It is thus not surprising that Honduras and other developing countries

now place considerable reliance on transferring risk outside the country to finance post-disaster reconstruction (Pollner, 2000). These risk transfers are provided either in the form of grants or loans by the governments of the developed world or through international financial institutions such as the World Bank, the regional development banks and UN agencies. The funding for post-disaster reconstruction has substantially increased in recent years. During the past four years, the Inter American Development Bank has increased its disaster-related lending by a factor of 10 compared to the previous 15 years (Clarke, 2000). The increasing demands of post-disaster reconstruction funding drive the interest of the international aid and financing community in exploring catastrophe hedges, including insurance, to transfer the risk of loss from natural catastrophes from governments in poorer countries to professional risk bearers: either insurance companies or the capital markets.

Role of Private Insurance

Two issues drive the interest of policy-makers to shift the burden of environmental risk from the government to other parties. The first concern is the limitation of public sector programs to encourage *ex ante* risk-reducing behavior. If residents in hazard-prone areas believe, sometimes incorrectly, that they will receive federal assistance following a disaster, they have less economic incentive to invest in loss prevention measures or insurance than if they knew they were going to have to bear the recovery costs themselves. Second, the assumption of risk by the government may be inappropriate, either as a matter of public policy or because the government is not in a position to absorb the risk. For example, in many developing countries the government assumption of homeowner risk provides a disincentive for homeowners to manage the risk on their own, either through private insurance or by risk mitigation strategies. Furthermore, the risk assumed by the government may be beyond its ability to finance the loss after a disaster. A major earthquake in some countries would be so destructive that the government commitment to fund housing reconstruction would be beyond its resources (Freeman et al., 2002). If the government is not the appropriate entity to absorb risk, the natural question is how may the risk be transferred? Increasingly, policy makers are exploring the voluntary shifting of environmental risk through insurance.

Historical perspective

Insurance has long played a role in developed societies as a risk-reducing and risk-spreading tool. The Code of Hammurabi, issued about 1950 BC, laid the basis for the institutionalization of insurance by formalizing the

concept of bottomry (Covello and Mumpower, 1985). Bottomry was the basis for maritime contracts on vessels, cargo, or freight that charged risk premiums between 10 and 25 percent of shipping costs to cover the chance of loss. Around 750 BC, the concept of risk sharing was formalized when all parties engaged in a shipping arrangement agreed to share proportionately in any loss suffered during the voyage.

Insurance temporarily disappeared from western civilization after the fall of the Roman Empire, but re-emerged in the form of marine insurance in Italian port cities around AD 1000. Insurance became more highly developed between the twelfth and fourteenth centuries as an integral component of the Hanseatic League's activities. Fire insurance, developed in London following the Great Fire of 1666, became extremely popular in England.

The best example of using private insurance as a viable means of spreading and reducing societal risk comes from the factory mutual insurance companies, founded in early nineteenth-century New England (Bainbridge, 1952). These mutual companies offered factories protection against potentially large losses from fire in return for a small premium. In order to reduce risk, the mutuals required inspections of a factory both before issuing a policy and after one was in force. Customers who were regarded as poor risks had their policies canceled; factories that instituted loss prevention measures received premium reductions.

As the mutual companies gained experience with fire risks, they set up research departments to determine what factors caused fires and how to reduce losses by concentrating on those factors. For example, the Boston Manufacturers' Mutual Company worked with lantern manufacturers to encourage them to develop safer designs and required policyholders to purchase lanterns only from companies whose products met their specifications. Manufacturers' Mutual hired researchers to find ways of reducing the risk of fire, for example developing non-flammable lubricating oils. It then shared these findings with key trade associations, and distributed educational pamphlets on preventing fires to textile mill owners.

In many cases, mutual companies would only offer insurance to companies that adopted specific loss prevention methods. For example, Spinners Mutual only insured factories that installed automatic sprinkler systems. Manufacturers' Mutual in Providence, Rhode Island, developed specifications for fire hoses and advised mills to buy only from companies whose hoses met those specifications. By researching and requiring loss prevention techniques and inspecting facilities before issuing or renewing a policy, nineteenth-century insurers were able to reduce losses dramatically and provide coverage against risks for which there had previously been no protection.

Historically, insurance has blended risk transfer with incentives to reduce risk. It is a unique policy tool in that it rewards individuals before a disaster for investing in loss reduction measures through lower premiums, as well as paying these same people for damages suffered from a disaster.

Characteristics of insurance

Insurance has five specific characteristics that make it effective in managing risk: ability to spread risk; capacity to reduce the variance of risk; segregation of risk; encouragement of loss reduction; and ability to monitor and control the behavior of the insured.

Risk spreading If a business bears the entire cost of losing its property to fire, the impact of such a loss on that business can be severe. If the business owns multiple properties, the damage to one facility diminishes the loss severity somewhat, because the business only loses part of its holdings. If the business pools its risk with other businesses through the purchase of fire insurance, it can experience a further reduction in the financial impact from a fire. As a result, insurance enables activities to take place that might not otherwise occur if the business were forced to bear individually the risk associated with the activity itself.

As the above discussion illustrates, insurance spreads the economic consequences of individual events (fire) across broader groups (many businesses). In so doing, it reduces the potentially catastrophic consequences of unforeseen events on an individual or business by having those consequences absorbed by a third party. The third party, usually an insurance company, collects premiums from many to pay for the unexpected losses of a few. Insurance tends to be self-funding, with the collected premiums held in reserve to pay future claims (Rejda, 1982).

Variance reduction Insurance markets normally exist because companies issue a large number of policies whose losses are independent of each other. If an insurer issues a large number of policies, then his expected losses illustrate the theory of 'the law of large numbers'. In simple terms, this law states that, as the number of independent events (here, losses) under consideration increases, the frequency distribution of those events tends toward the normal distribution. Therefore, the mean or expected value of the events (losses) and their variance (or measure of dispersion) are sufficient to describe the distribution of events. Furthermore, the variance of the mean value decreases as the number of events increases. If we view the variance as a measure of volatility or risk of loss, then the risk associated with the loss reduces as the number of policies grows.

As long as the number of policies issued is reasonably large, an insurer

can charge premiums for disaster events that are independent of each other by estimating their mean loss or expected loss. Fire and automobile coverage are two examples of catastrophe risks that tend to be independent. Notable exceptions include the 1991 Oakland fire that destroyed 1941 single-unit dwellings and damaged 2069 others or a major accident on a freeway involving many cars. Natural hazards, however, create problems for insurers because the losses arising from these events are rarely independent. The law of large numbers does not apply here (Kunreuther and Grossi, in press).

For example, if a severe earthquake occurs in Los Angeles, there is a high probability that many structures will be damaged or destroyed simultaneously. If an insurer had 1000 policies in this one region, then the estimated variance of his losses would be much larger than if these policies were written in 1000 different cities across the USA.

Segregation of risks Insurance works best when it segregates risk. This involves discriminating between different classes of potential policyholders, using such identifying features as characteristics of the individual (good drivers versus bad drivers), classes of business (trucks versus recreational automobiles), or groups with different risk exposure (general contractors versus hazardous waste removal contractors).

Segregation enables insurance providers to separate the lowest risk category (good drivers) from a risk pool (all drivers) and to price and sell policies separately to members of that category. Safe drivers, for example, would pay an amount based on their risk profile rather than being charged a rate that subsidizes those drivers with accident records.

Encouraging loss reduction measures In the process of creating uniform risk categories, insurance companies have adopted techniques for modifying the behavior of potential insureds. The insurer, taking a cue from the nineteenth-century mutual companies, will often require its potential policyholders to undertake specific loss reduction activities before receiving insurance coverage. In fact, insurance companies have often been the driving force behind the implementation of safety procedures. As discussed in the section on the history of insurance, as new protective measures reduced the incidence of fire in the workplace during the nineteenth century, for example, fire risk was reduced, as were the overall costs to society (Bainbridge, 1952).

Insurers also offer premium reductions to individuals and businesses who have taken actions to reduce their risks or have better-than-average records regarding their past performance. Life insurance, for example, costs less for nonsmokers than for smokers. Security systems, burglar-proof

safes, and other loss prevention devices lower insurance premiums (Greene and Trieschmann, 1988). Auto insurance costs less for drivers who have not had an accident in several years. Insurers design these forms of experience rating to encourage behavior that reduces overall risk exposure.

Monitoring and control Insurers also provides a valuable function by monitoring the activities of their policyholders. Insurance providers generally undertake this monitoring function to verify that the insured operates in a manner consistent with underwriting standards. Monitoring may be as simple as verifying driving records, or as complicated as inspecting manufacturing facilities.

The insurer will not always undertake the inspection or audit itself but may hire certified inspectors or experts for this purpose. For example, after some serious accidents involving steam boilers in the nineteenth century, insurers used certified inspectors to monitor and approve boiler designs. Once these inspectors performed their work, insurers offered policies to cover any losses from a boiler explosion. The insurer knew a low probability of such an event existed given the certification process. In fact, the monitoring of operations by the insurance provider can have significant benefit for other parties, such as the government, interested in having the behavior of others reviewed. For nearly 100 years, operators of steam boiler vessels in the USA have met government regulations by securing insurance certificates for those boilers.

Insurance has a number of inherent qualities that promise to reduce future risks and provide compensation if a loss occurs. Policy-makers have expressed significant interest in the use of insurance as a policy tool to complement the existing use of government benefit programs as a tool to transfer risk. However, the risks in question have to meet the conditions of insurability for this policy tool to be applicable.

2. INSURABILITY OF RISKS[3]

What does it mean to say that a particular risk is insurable? This question must be addressed from the vantage point of the potential supplier of insurance who offers coverage against a specific risk at a stated premium. The policyholder is protected against a prespecified set of losses defined in the contract.

Two conditions must be met before insurance providers are willing to offer coverage against an uncertain event. Condition 1 is the ability to identify and quantify, or estimate, the chances of the event occurring, and the extent of losses likely to be incurred when providing different levels

of coverage. Condition 2 is the ability to set premiums for each potential customer or class of customers. This requires some knowledge of the customer's risk in relation to others in the population of potential policyholders.

If Conditions 1 and 2 are both satisfied, a risk is considered to be insurable. But it still may not be profitable. In other words, it may impossible to specify a rate for which there is sufficient demand and incoming revenue to cover the development, marketing and claims costs of the insurance and yield a net positive profit. In such cases the insurer will opt not to offer coverage against this risk.

Condition 1: Identifying the Risk

To satisfy this condition, estimates must be made of the frequency at which specific events occur and the extent of losses likely to be incurred. Such estimates can use data from previous events, or scientific analyses of what is likely to occur in the future. One way to reflect what experts know and do not know about a particular risk is to construct a loss exceedance probability (EP) curve.

A loss EP curve depicts the probability that a certain level of loss will be exceeded on an annual basis. The loss can be reflected in terms of dollars of damage, fatalities, illness or some other measure. To illustrate with a specific example, suppose one was interested in constructing an EP curve for dollar losses from a catastrophic chemical accident. Using probabilistic risk assessment one combines the set of events that could produce a given dollar loss and then determines the resulting probabilities of exceeding losses of different magnitudes.

Based on these estimates, one can construct the mean EP depicted in Figure 4.2. By its nature, the EP curve inherently incorporates uncertainty in the probability of an event occurring and the magnitude of dollar losses. This uncertainty is reflected in the 5 percent and 95 percent confidence interval curves in Figure 4.2.

The EP curve is the key element for evaluating a set of risk management tools. The accuracy of the EP curves depends upon the ability of the scientific and engineering community as well as social scientists to estimate the impact of events of different probabilities and magnitudes using the different units of analysis. These units normally include quantifiable measures such as dollar damage, number of people injured or killed and business interruption losses.

When dealing with extreme events the key question that needs to be addressed when constructing an EP curve is the degree of uncertainty with respect to both the probability and the consequences of the event. It is

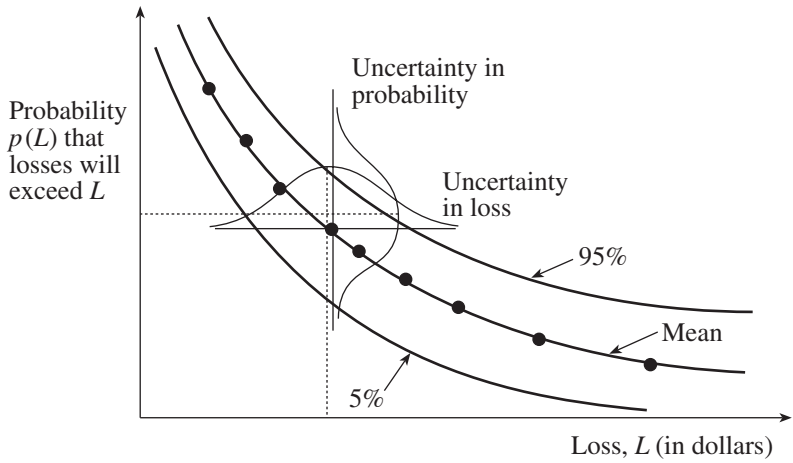


Figure 4.2 Example of exceedance probability curves

much easier to construct an EP curve for natural disasters and chemical or nuclear power plant accidents than it is for terrorist activities. But even for these more predictable events there is considerable uncertainty with respect to both the probability of occurrence and the resulting losses. Here are a few questions in this regard to ponder:

- What are the chances that there will be a chemical accident that kills more than 100 people somewhere in the world during the next year and what will be the resulting damage and indirect losses?
- What is the likelihood of a major hurricane striking the most populated portions of the Florida coastline in the next ten years and what would be the damages from this event?
- What are the chances that there will be a cancer epidemic due to leakages from underground storage tanks in the next five years and how many people would be affected?

Condition 2: Setting Premiums for Specific Risks

Once the risk has been identified, the insurer needs to determine what premium it can charge to make a profit while not subjecting itself to an unacceptably high chance of a catastrophic loss. There are a number of factors that influence this decision. In the discussion which follows we are assuming that insurers are free to set the premiums at any level they wish. In reality, state regulations often limit insurers in their rate-setting process.

Ambiguity of risk

Not surprisingly, the higher the uncertainty regarding the probability of a specific loss and its magnitude, the higher the premium will be. As shown by a series of empirical studies, actuaries and underwriters are so averse to ambiguity and risk that they tend to charge much higher premiums than if the risk were well specified. Kunreuther et al. (1995) conducted a survey of 896 underwriters in 190 randomly chosen insurance companies to determine what premiums would be required to insure a factory against property damage from a severe earthquake. The survey results examine changes in pricing strategy as a function of the degree of uncertainty in either the probability and/or loss.

A probability is considered to be well specified where there is enough historical data and/or scientific information on the nature of the event that all experts agreed that the probability of a loss is p. When there is wide disagreement about the estimate of p among the experts, this ambiguous probability is referred to as Ap. L represents a known loss – that is, there is a general consensus about what the loss will be if a specific event occurs. When a loss is uncertain, and the experts' estimates range between $L_{\min}$ and $L_{\max,}$ this uncertain loss is denoted as UL.

Combining the degree of probability and loss uncertainty leads to four cases that are shown in Table 4.1 along with a set of illustrative examples of the types of risks that fall in each category.

Table 4.1 Classification of risks by degree of ambiguity and uncertainty

	Loss	
Probability	Known	Unknown
Well specified	*Case 1* p, L Life, auto, fire	*Case 3* p, UL Playground accidents
Ambiguous	*Case 2* Ap, L Satellite	*Case 4* Ap, UL Earthquake, bioterrorism

To see how underwriters reacted to different situations, four scenarios for an earthquake risk were constructed as shown in the columns of Table 4.2. Where the risk is well specified, the probability of the earthquake is either 0.01 or 0.005; the loss, should the event occur, is either $1 million or $10 million. The premium set by the underwriter is standardized at 1 for the non-ambiguous case; one can then examine how ambiguity affects pricing decisions.

Table 4.2 Ratios of underwriters' actuarial premiums for ambiguous and/or uncertain earthquake risks relative to well-specified risks

	Cases			
Scenario	1 *p*, *L*	2 *Ap*, *L*	3 *p*, *UL*	4 *Ap*, *UL*
$p = 0.005$ $L =$ \$1 million $pL =$ \$5,000	1	1.28	1.19	1.77
$p = 0.005$ $L =$ \$10 million $pL =$ \$50000	1	1.31	1.29	1.59
$p = 0.01$ $L =$ \$1 million $pL =$ \$10000	1	1.19	1.21	1.50
$p = 0.01$ $L =$ \$10 million $pL =$ \$100000	1	1.38	1.15	1.43

Source: Kunreuther et al. (1995).

Table 4.2 shows the ratio of the other three cases relative to the non-ambiguous case (*p*, *L*) for the four different scenarios, which were distributed randomly to underwriters in primary insurance companies. For the highly ambiguous case (*Ap*, *UL*), the premiums were between 1.43 to 1.77 times higher than if underwriters priced a non-ambiguous risk. The ratios for the other two cases were always above 1, but less than the (*Ap*, *UL*) case.

These concerns with the ambiguity and uncertainty of the risks have been brought to the fore since 11 September 2001, when insurers have been concerned with providing coverage against terrorism because they feel that the probability of another attack is highly ambiguous and the losses very uncertain. During the fall of 2001 it was not unusual for investors to require an annual return on investment as high as 20 percent to invest in terrorist coverage because they were so concerned with the ambiguity of the risk (Kunreuther, 2002).

Adverse selection[4]

If the insurer sets a premium based on the average probability of a loss, using the entire population as a basis for this estimate, those at the highest

risk for a certain hazard will be the most likely to purchase coverage for that hazard. In an extreme case, the poor risks will be the only purchasers of coverage, and the insurer will lose money on each policy sold. This situation, referred to as adverse selection, occurs when the insurer cannot distinguish between the probabilities of a loss for good- and poor-risk categories.

The assumption underlying adverse selection is that purchasers of insurance have an informational advantage by knowing their risk type. Insurers, on the other hand, must invest considerable expense to collect information to distinguish between risks. For example, suppose some homes have a low probability of suffering damage (the good risks), and others have a higher probability (the poor risks). The good risks stand a 1 in 10 probability of loss and the poor risks a 3 in 10 probability. For simplicity, assume that the loss, is \$100 for both groups and that there is an equal number of potentially insurable individuals in each risk class.

Since there is an equal number in both risk classes, the expected loss for a random individual in the population is \$20.[5] If the insurer charges the actuarially fair premium across the entire population, only the poor-risk class would normally purchase coverage, since their expected loss is \$30 ($0.3 \times \$100$), and they would be pleased to pay only \$20 for the insurance. The good risks have an expected loss of \$10 ($0.1 \times \$-100$), so they would have to be extremely risk-averse to want to pay \$20 for coverage. If only the poor risks purchase coverage, the insurer will suffer an expected loss of $-\$10$ (that is, \$20–\$30) on every policy it sells.

There are three principal ways that insurers can deal with this problem. The insurer can raise the premium to at least \$30 so that it will not lose money on any individual purchasing coverage. In reality, where there is a spectrum of risks, the insurer may only be able to offer coverage to the worst-risk class in order to make a profit. Hence, raising premiums in this way is likely to deprive a large segment of the population from buying insurance because the going rate will be too high. This is a type of market failure. Rothschild and Stiglitz (1976) proposed a second way for the insurer to deal with adverse selection. It could offer two different price-coverage contracts. For example, contract 1 could be offered at Price = \$30 and Coverage = \$100, while contract 2 might be Price = \$10 and Coverage = \$40. If the poor risks preferred contract 1 over 2, and the good risks preferred contract 2 over 1, this would be one way for the insurers to market coverage to both groups while still breaking even.

A third approach is for the insurer to require some type of audit or examination to determine the nature of the risk more precisely. However, inspections and audits are expensive and will raise the premium charged unless the potential policyholder pays for the audit.

Moral hazard[6]

Providing insurance protection to an individual may lead that person to behave more carelessly than before he or she had coverage. If the insurer cannot predict this behavior and relies on past loss data from uninsured individuals to estimate rates, the resulting premium is likely to be too low to cover losses.

Moral hazard refers to an increase in the probability of loss caused by the behavior of the policyholder. Obviously, it is extremely difficult to monitor and control behavior once a person is insured. How do you monitor carelessness? Is it possible to determine if a person will decide to collect more on a policy than he or she deserves by making false claims?

The numerical example used above to illustrate adverse selection can also demonstrate moral hazard. With adverse selection the insurer cannot distinguish between good and bad risks, but the probability of a loss for each group is assumed not to change after a policy is sold. With moral hazard the actual probability of a loss becomes higher after a person becomes insured. For example, suppose the probability of a loss increases from $p = 0.1$ before insurance to $p = 0.3$ after coverage has been purchased. If the insurance company does not know that moral hazard exists, it will sell policies at a price of \$10 to reflect the estimated actuarial loss ($0.1 \times \$100$). The actual loss will be \$30 since p increases to 0.3. Therefore, the firm will lose \$20 (\$30–\$10) on each policy it sells.

One way to avoid the problem of moral hazard is to raise the premium to \$30 to reflect the known increase in the probability, p, that occurs once a policy has been purchased. In this case there will not be a decrease in coverage as there was in the adverse selection example. Those individuals willing to buy coverage at a price of \$10 will still want to buy a policy at \$30 since they know that their probability of a loss with insurance will be 0.3.

Another way to avoid moral hazard is to introduce deductibles and co-insurance as part of the insurance contract. A sufficiently large deductible can act as an incentive for the insureds to continue to behave carefully after purchasing coverage because they will be forced to cover a significant portion of their loss themselves. With co-insurance the insurer and the insured share the loss together. An 80 percent co-insurance clause in an insurance policy means that the insurer pays 80 percent of the loss (above a deductible), and the insured pays the other 20 percent. As with a deductible, this type of risk-sharing arrangement encourages safer behavior because those insured want to avoid having to pay for some of the losses.[7]

Another way of encouraging safer behavior is to place upper limits on the amount of coverage an individual or enterprise can purchase. If the insurer will only provide \$500 000 worth of coverage on a structure and

contents worth $1 million, then the insured knows he or she will have to incur any residual costs of losses above $500 000. This assumes that the insured will not be able to purchase a second insurance policy for $500 000 to supplement the first one and hence be fully protected against a loss of $1 million, except for deductibles and insurance clauses. One could also discourage moral hazard by restricting the number of claims before one canceled or refused to renew one's policy. If the claims have been very costly to the insurer they could also raise the premium from what it was in the previous year.[8]

Even with these clauses in an insurance contract, the insureds may still behave more carelessly with coverage than without it simply because they are protected against a large portion of the loss. For example, they may decide not to take precautionary measures that they would have adopted had they been uninsured. The cost of adopting mitigation may now be viewed as too high relative to the dollar benefits that the insured would receive from this investment. If the insurer knows in advance that an individual will be less interested in loss reduction activity after purchasing a policy, then it can charge a higher insurance premium to reflect this increased risk or it can require specific mitigation measures as a condition of insurance. In either case this aspect of the moral hazard problem will have been overcome.

Correlated risk

The simultaneous occurrence of many losses from a single event raises the possibility of insurer insolvency and/or a severe financial crisis to the firm. As pointed out earlier, natural disasters such as earthquakes, floods and hurricanes produce highly correlated losses: many homes in the affected area are damaged and destroyed by a single event.

If a risk-averse insurer faces highly correlated losses from one event, it may want to set a high enough premium not only to cover its expected losses but also to protect itself against the possibility of experiencing catastrophic losses. An insurer will face this problem if it has many eggs in one basket, such as providing earthquake coverage mainly to homes in Los Angeles County rather than diversifying across the entire state of California.

To illustrate the impact of perfectly correlated risks on the distribution of losses, assume that there are two policies sold against a risk where $p = 0.1$, $L = \$100$. The actuarial loss for each policy is $10. For perfectly correlated losses, there will be either two claims with probability of 0.1 or no claims with a probability of 0.9. On the other hand, if the losses are independent of each other, then the chance of two losses decreases to 0.01 (that is, 0.1×0.1), with the probability of no losses being 0.81 (that is, 0.9×0.9).

There is also a 0.18 chance that there will be only one loss (that is, $0.9 \times 0.1 + 0.1 \times 0.9$).

In this example the expected loss for both the correlated and uncorrelated risks is \$20.[9] However, the variance will always be higher for correlated than uncorrelated risks if each have the same expected loss. Thus risk-averse insurers will always want to charge a higher premium for the correlated risk (Hogarth and Kunreuther, 1992).

Insurability Conditions and Demand for Coverage

The above discussion suggests that in theory insurers can offer protection against any risk that they can identify, and for which they can obtain information to estimate the frequency and magnitude of potential losses as long as they have the freedom to set premiums at any level. However, due to problems of ambiguity, adverse selection, moral hazard and highly correlated losses, they may want to charge premiums that considerably exceed the expected loss.

For some risks the desired premium may be so high that there would be very little demand for coverage at that rate. In such cases, even though an insurer determines that a particular risk meets the two insurability conditions discussed above, it will not invest the time and money to develop the product. More specifically, the insurer must be convinced that there is sufficient demand to cover the development and marketing costs of the coverage through future premiums received.

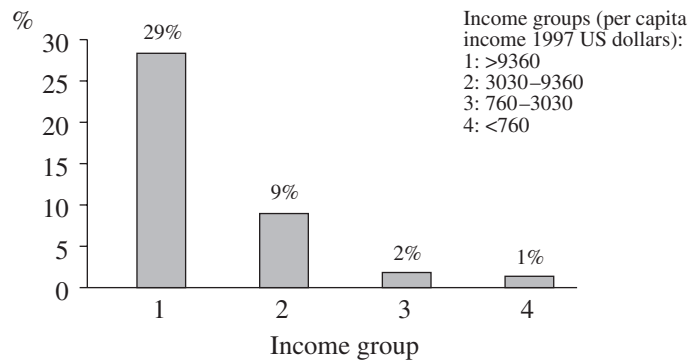
If there are regulatory restrictions that limit the price insurers can charge for certain types of coverage, then companies will not want to provide protection against these risks. In addition, if an insurer's portfolio leaves them vulnerable to the possibility of extremely large losses from a given disaster due to adverse selection, moral hazard and/or high correlation of risks, then the insurer will want to reduce the number of policies in force for these hazards.

3. EXAMPLES OF MANAGING ENVIRONMENTAL RISK THROUGH INSURANCE

This section illustrates how insurance has been utilized to manage environmental risk. The first example looks at the use of insurance as a component of a comprehensive risk management program for natural disasters. The second examines a current proposal to use insurance and third-party inspections to enforces one of the provisions of the Clean Air Act amendments of 1990 in the USA.

Insurance and Natural Hazard Management in Developing Countries[10]

A fundamental distinction between the risk management policies in the developed world and in developing countries is the role of risk transfer. The developed countries use risk transfer through the insurance mechanism as a major component of their natural disaster risk strategy. As shown Figure 4.3, 29 percent of their losses from natural hazards are insured. In the poorest countries, insurance covers 1 percent of the losses from natural hazards.



Source: Munich Re (2002), pp. 24–5.

Figure 4.3 Ratio of insured losses to total losses according to country income groups for period 1985–99

There is considerable worldwide activity in promoting different government-based programs for shifting the risk to those who reside in hazard-prone areas. As mentioned above, Turkey has a recent insurance program to transfer risk from earthquakes to property owners residing in seismically active parts of the country. Proposals are being explored in Mexico, the Caribbean, Central America and Africa to engage the government in providing risk-transfer options for farmers, homeowners and businesses in case of natural-catastrophe losses (World Bank, 2000). The Caribbean Disaster Mitigation Project (CDMP) commissioned a study to explore insurance options for small states in the region (Pollner, 2000). The World Bank has proposed the creation of a new insurance program for Honduras. As a component to the recently announced Puebla to Panama initiative sponsored by Mexico, the Inter American Development Bank is considering regional insurance options for Central America (IDB, 2002).

The use of insurance as an effective policy tool to enable countries to deal

with risk more efficiently is a major theme in the current development literature. The 2000/2001 *World Development Report* on Poverty devotes considerable attention to the role of insurance in enabling countries to deal better with risk, including the risk from natural catastrophes (World Bank, 2000).

Barriers to supplying catastrophe insurance

It is no coincidence that insurance is an economic tool used by wealthy countries. It requires sophisticated financial institutions to operate. Insurance requires a complex series of laws, regulations and administrative agencies. Those include the proper financial structure of insurance companies to ensure their financial capacity to pay future claims and the actuarial science (including the required information base) that underpins the setting of premiums and reserves. One also needs legal knowledge about insurance contracts and proper legal institutions to enforce sophisticated contractual agreements. To market coverage and settle claims one needs a distribution network and qualified loss adjustors.

Designing major institutional reforms to permit the proper operation of financial institutions is very difficult. For example, the reform of the banking sector in Mexico increased its vulnerability to financial crises. For example, the crises suffered by Mexico in 1995 can be traced to a weak banking system, its fragility traced to the privatization process used for the banks, some aspects of the financial liberalization program, and the weak regulatory institutions (World Bank, 2000).

In addition to the need for institutional reforms, there are issues related to the fundamental structure of the market for insurance. For example, many countries may be too small to provide adequate risk diversification to properly support a national insurance scheme. Proposals to create regional insurance markets hope to increase risk diversification and potential market size, thereby making the market more attractive for the insurance industry and lowering the cost of insurance. For example, proposals exist to create a regional natural-hazard insurance market for the eastern Caribbean. Since the region is populated with small island countries with high covariant risk, the pooling of each country's risk into a regional pool is likely to increase the availability of insurance (Pollner, 2000).

A larger potential market subject to a uniform regulatory scheme may encourage the international insurance industry to help develop viable markets. To the extent that small countries in a region have varied regulatory policies, it provides a barrier to insurance companies offering coverage for similar risks in the region. The costs associated with developing premiums and marketing coverage may make it prohibitively expensive for firms to market insurance for what is likely to be limited demand for the

product. Regional proposals like the Puebla to Panama catastrophe insurance initiative for all of Central America and Mexico are partially based on overcoming impediments to the supply of insurance. Since Central America is populated with small countries each with high natural-hazard risk, the creation of a regional market that offers insurance to anyone within the region is viewed as an alternative to diversifying risk across the region. In so doing, it is hoped that the availability of insurance against natural hazard risk for each country will be increased over what is now offered to each individual country in the region. Since the regional market is larger and more diversified than each separate-country market, there should be more incentive for insurance companies to develop and offer natural-hazard insurance in the region.

Demand for insurance in poorer countries

In truth, the problem with developing risk transfer as an effective policy tool is more related to a lack of demand for catastrophe insurance. In poorer countries, large-scale businesses can and do buy catastrophe insurance. In Mexico, nearly 100 percent of industrial enterprises buy insurance (Kreimer et al., 1999). Worldwide, the strongest demand for insurance is from medium-sized businesses and homeowners. Since most developing countries do not have either a substantial middle class (who are homeowners) or many medium-sized businesses, there is a small natural clientele for insurance.

Professional risk bearers, like insurance companies, are fully capable of modifying their products to adapt to local needs. However, there will be little willingness on their part to do so if limited demand exists for the modified products. One direct approach to creating demand is to make insurance mandatory. Turkey has adopted this strategy in requiring homeowners to purchase earthquake insurance. France and Spain also make participation in their natural disaster insurance programs mandatory (Gulkan, 2000).

Because of the relatively high administrative costs associated with marketing insurance and budget constraints facing the low-income residents in developing countries, this type of protection is not a viable option for this group. There is much that can be done to support the poor outside the establishment of a formal insurance program. The main strategy for the poor to deal with external shocks requires a poverty-sensitive policy that focuses on the following components:

- Helping poor households maintain their consumption.
- Ensuring that poor people do not lose whatever access they have to basic social services.

- Preventing permanent reversals in the accumulation of human and physical capital.
- Averting self-defeating behavior, such as criminal activity, prostitution, and exploitative forms of child labor (World Bank, 2000).

Among the most effective programs are workfare programs introduced or expanded in the disaster area in conjunction with post-disaster reconstruction.

Disaster management in Fiji

One developing country that looked to tie insurance as a major component of its risk management strategy for natural hazards is Fiji. Fiji is a developing country with extensive natural-catastrophe exposure from cyclones, floods, droughts, earthquakes and tsunamis. Fiji has moved remarkably towards an integrated system for disaster risk management that includes a strong national program and plan, involvement by private insurers, and a keen awareness that non-governmental organizations (NGOs) and local efforts are an integral part of the system (Benson, 1997).

Fiji's national disaster management program began as an *ad hoc* governmental committee for emergency response, but by 1990, the national program was restructured to make it more comprehensive, covering prevention, mitigation, preparedness and rehabilitation activities in addition to emergency response. In 1995 the government published the National Disaster Management Plan (Government of Fiji, 1995), which laid out a comprehensive policy and detailed the supporting roles of NGOs in all the functions of disaster management.

For a poor country, private insurance plays an important role in Fiji's national strategy. Since Fiji has a thriving tourism industry, it is not surprising that private insurance has a very high uptake in the business sector, whereas there is less but still significant insurance cover for private urban dwellings. The purchase of insurance is a key strategy to permit the tourism industry to remain in business despite the likelihood of recurrent tsunamis.

Insurers take a proactive role in mitigation and prevention. After particularly severe cyclones in 1984, the Commissioner of Insurance established the Fiji Building Standards Committee, made up mainly of private insurers. This committee had the responsibility to oversee the preparation of a national building code that would set minimum standards to reduce disaster-related losses and help achieve a stable or reduced hurricane insurance premium (Government of Fiji, 1985). Upgraded homes are inspected by a structural engineer and issued a certificate; they are required to obtain cyclone insurance cover. Most urban areas have adopted the building code (Rokovada and Vrolijks, 1993).

A number of other emerging and developing countries have integrated insurance into their national strategies to cope with natural-hazard risk. Barbados and Mexico both require that all government-owned buildings be insured (Freeman et al., 2001). Mexico has a fund for natural disasters that reimburses local governments and private property owners for a portion of their losses from natural catastrophes (Kreimer and Arnold, 1998).

While the challenges to using insurance to cope with natural-hazard risk are difficult, the limited successes of a number of developing and emerging countries to initiate new programs has created greater interest in the role that insurance can play in managing natural-hazard risk.

Insurance coupled with third-party inspections[11]

The passage of Section 112(r) of the Clean Air Act Amendments (CAAA) of 1990 offers an opportunity to utilize insurance coupled with third-party inspections to encourage firms to reduce their risks from accidents and disasters. This legislation created two new federal regulatory programs aimed at preventing releases of hazardous chemicals: the Occupational Safety and Health Administration (OSHA) Process Safety Management (PSM) standard and the US Environmental Protection Agency (EPA) Risk Management Program.

The PSM standard was enacted in 1992 and requires facilities containing large quantities of highly hazardous chemicals to implement accident prevention and emergency response measures to protect workers. The EPA Risk Management Program regulation, published in 1996, borrowed the same accident prevention concepts and language from PSM but went beyond the OSHA program. It also required facilities to perform a hazard assessment, estimate consequences from accidents and submit a summary report to EPA by 21 June 1999 called the Risk Management Plan (RMP) (Belke, 2001). The challenge is how to encourage compliance of these regulations.

Use of insurance with third parties to enforce regulation

Consider an industrial facility that has a relatively high probability (p_h) of causing an accident which results in a loss (L), where L is a multidimensional vector reflecting direct impacts, which include lives lost or injured and damage to physical property. In addition there may be negative externalities in the form of environmental and social impacts (for example decreases in property values and disruptions in community life) that are not borne by the firm.[12]

The firm has an opportunity to reduce L as well as these negative externalities arising from accidents by implementing a risk management plan (RMP) that will reduce the probability of an accident to $p_l < p_h$ at a fixed

cost C. The magnitude of C is based on the expenditures in both time and money in implementing a strategy for reducing the risks of future accidents.

EPA and other regulatory agencies have been searching for ways to ensure a high compliance level with respect to their regulations and standards. Consider the case of enforcing Section 112(r) of the CAAA of 1990. Given the potentially severe negative externalities associated with accidents and EPA's limited personnel and funds for providing technical guidance and auditing regulated facilities,[13] there is some urgency for a type of decentralized procedure with appropriate incentives.

Chemical firms, particularly smaller ones, may have little financial incentive to follow centralized regulatory procedures if they estimate that the chances that they will be inspected by a regulatory agency are very small and/or they know the fine should they be caught will be low. To see this, suppose that the cost of investing in an RMP is C and the discounted expected benefits are $E(B) < C$, so that the firm perceives that the net expected loss to them of investing in an RMP will be $E(L) = C - E(B)$. Suppose that the chance that a regulatory agency will inspect a firm is p. If the firm is found not to have implemented an RMP, then it will be fined F and be required to incur the investment cost C. The expected cost to the firm of not implementing an RMP is thus $p\,(F + C)$. A risk-neutral firm will not want to invest in an RMP if $p(F + C) < E(L)$. Smaller firms with asset levels $A < F + C$ will have even less reason to invest in an RMP, preferring to declare insolvency should they be caught.[14]

The combination of a mandatory private insurance in conjunction with third-party inspections is a powerful combination of two market mechanisms that can convince many firms of the advantages of implementing RMPs to make their plants safer and encourage the remaining ones to comply with the regulation to avoid being caught and fined. Such a program would reduce societal risk due to the negative externalities associated with accidents, while providing a tool for the government to help ensure compliance at minimal regulatory cost.

To show the conditions under which third parties can be effective, Kunreuther et al. (2002) have developed a simple model where there are two types of firms – high and low risk. Firms are assumed to maximize their expected profits. The probability of an accident is p_l for a low-risk firm and p_h for a high risk firm ($p_l < p_h$). The losses from an accident are L whether the firm is low or high risk.

In this model firms are required to have insurance to cover their losses should a catastrophic accident occur. Financial institutions may require insurance as a condition for a mortgage to protect the bank's investment. The regulatory agency could require this coverage, so that the firm will not declare insolvency should it suffer a severe loss from an accident.

If a firm agrees to be audited, the third party will charge C for the inspection and the insurer will charge a premium that reflects the outcome of the inspection. A low-risk firm will be charged $p_l L$ and a high risk firm will be charged $p_h L$. If the firm refuses to be audited, it will be presumed to be high risk and will be charged a higher premium.

The intuition behind using third parties and insurance to support regulations can be stated in the following way. One of the biggest concerns of a regulatory agency (RA) is that it doesn't have enough resources to audit all firms in the industry. Low-risk firms, which the RA has no need to audit, cannot credibly distinguish themselves from the high-risk ones without some type of inspection. By delegating part of the inspection process to the private sector through insurance companies and third parties, the RA provides a channel though which the low-risk firms can speak for themselves. If a firm chooses not to be inspected by third parties, it is more likely to be a high- rather than a low-risk one. Therefore this mechanism not only substantially reduces the number of firms the RA has to audit, but it also makes their audits more efficient.

The Kunreuther et al. (2002) paper suggests that the government fine associated with a regulatory audit needs to be carefully considered as a part of the policy process. If there is a small chance that a firm will be audited, then F has to be much larger than if p were relatively high. There is likely to be political pressure from the regulated industry for low fines, since small firms may have to declare insolvency if F is too high. To the extent that third parties provide other risk management services, then voluntary inspection becomes a more attractive option for any given (p, F) combination.

Success of insurance and third-party inspections

Steam boiler insurance and inspections provide a convincing illustration of the use of these two policy tools for reducing risks of explosions. The Hartford Steam Boiler Inspection and Insurance Company (HSB) initiated inspections coupled with insurance in the 1860s after a severe boiler explosion on the Mississippi River. HSB has always stressed that insurance was secondary to loss prevention, with engineering and inspection services making up a large part of the insurance premium. In an effort to reduce future risks, HSB undertook studies of boiler construction, which eventually led to boilermakers adopting safer designs (Er, 1996).

One of the key elements leading to the reduction in the number of boiler accidents is that all the states in the USA require annual inspections of pressure vessels by a representative licensed by the state, county or municipality in which the facility is located. Inspectors are qualified by either a formal examination or through a certificate of competency issued by the National Board of Boiler and Pressure Vessel Inspectors.[15]

Workers' compensation provides a second example of the role that insurance and third-party inspections can play in improving the safety of the workplace. Today almost every worker in the USA is covered by some kind of workers' compensation insurance system. Moore and Viscusi (1990) show that workers compensation has created substantial incentives for firms to promote safety. Since premiums are usually linked to performance, firms have financial incentives to invest in reducing risk levels.

The workers' compensation mechanism has some similarities to the model described above for those who choose to purchase coverage from insurers.[16] Insurance companies may undertake an inspection, although it is not mandatory that they do so, and firms pay premiums based on their risk level. The insurer may offer risk management services, often at a fee, to reduce a company's losses and its premium. The types of accidents considered in this paper (for example, chemical explosions, chemical fires, or chemical releases) usually generate more costs to the external world than do workplace hazards. Large-scale industrial accidents often impact on the whole neighborhood and surrounding area, while workers' accidents are normally confined to the employees in the firm.

Delaware and Pennsylvania pilot experiments

Over the past two years two pilot studies on third parties and insurance have been undertaken by a task force convened by the Wharton Risk Management and Decision Processes Center consisting of the EPA's Chemical Emergency Preparedness and Prevention Office (CEPPO), EPA Region III and the State of Delaware's Department of Natural Resources and Environmental Control (DNREC).[17]

Third-party auditors have been used to examine RMPs and ensure compliance with Section 112(r) of the CAAA in Delaware and Pennsylvania at both water chlorination and ammonia refrigeration facilities.[18] Ammonia and chlorine were the chemicals selected in the experiment because they represent 50 percent of the hazardous chemicals that facilities report under section 112(r) of the CAAA and because the task force was confident that the third-party auditors could be trained to conduct audits in chlorine and ammonia facilities in a two-day training period.

In both Delaware and Pennsylvania the owners and operators of facilities were sympathetic to having third-party inspections and would be inclined to use them if they yielded certain benefits. More specifically, facility owners said they would be especially interested if the EPA or a regulatory agency gave them a seal of approval based on the results of the inspection, if economic benefits were offered them by the insurance companies in undertaking the inspection, and if the community viewed positive results from an inspection as a signal that the firm was operating safely.

These pilot experiments indicate some of the additional actions that EPA must consider if it modifies the provisions of section 112(r) of the Clean Air Act Amendments to allow for third-party auditors to be used on a national basis. For one thing the agency needs to establish a certification mechanism for the selection and training of third-party auditors. It also needs to expand the selection and training of third-party auditors to include all chemicals listed on the EPA list, not just ammonia and chlorine. The agency also has to address the issue as to actions that need to be taken if an inspector discovers that the firm is operating in way that may be hazardous to employees and/or residents in the region.[19]

Where do we go from here?

By linking a required insurance policy with a third-party inspection there is an opportunity to convince both large and small firms that it is worthwhile for them to undertake an RMP and submit voluntarily to an inspection. This action will be particularly attractive if the inspector can provide special risk management services in addition to its audit function.

In addition, it is important for the regulatory agency to be able to charge an appropriate penalty if a firm is not in compliance. For example, if the US EPA imposes the maximum allowable fine of $27 500 per day should it discover that a firm does not have an RMP, then this may be an added incentive for industrial facilities to undertake a third-party inspection voluntarily.

The implicit assumption is that if a high-risk firm undertakes an inspection and does not want to incur the costs associated with investing in a process to make it a low-risk enterprise, then it not be required to do so. Furthermore, there is no obligation by the firm or the third party to report the results of the inspection to the regulatory authority. In practice there may need to be exceptions to this rule. For example, if an inspector finds that a facility poses a hazard where employees in the firm are in imminent danger, then he would be torn between maintaining confidentiality with the client and exposing individuals to possible injury or death.

One way to deal with this situation would be to require the inspector to reveal this information to the relevant regulatory authority if the firm refuses to take any remedial action within a prespecified period of time. Such a procedure would be in line with current OSHA policy for consultants to the agency who discover such a situation (Occupational Safety and Health Administration, 1989). More studies need to be undertaken to determine in what situations inspectors have an obligation to reveal the results of their findings to employees, citizens and/or the regulatory authority.[20]

The use of third-party inspections has had very beneficial effects on reducing the risks associated with different activities. Steam boiler acci-

dents have been very rare ever since it was required that boilers be inspected. If the safety incentives of workers' compensation were removed, there would be an increase of over 30 percent in fatality rates in the USA This translates into an increase of 1200 workers who would die from job-related accidents (Viscusi, 1991).

5. CONCLUSIONS

This chapter makes the case for using insurance coupled with other policy tools for reducing future losses from environmental risks. Our focus has been on losses from natural hazards and risks associated with catastrophic losses from industrial facilities, although these concepts can be applied to other areas as well. To date the public sector provides some relief to victims of natural disasters in all parts of the world and assumes much of the burden in emerging economies. With respect to reducing losses from large-scale industrial accidents, there have been regulations passed to reduce these losses, but the relevant agencies do not have sufficient person power to enforce them.

Insurance is a risk transfer instrument that has the added benefit of encouraging those seeking financial protection to take steps to reduce future losses since this will lower their annual premium. We discussed the conditions for making a risk insurable and the challenges in obtaining sufficient data to quantify the risk. In addition, the resulting premium has to be low enough to be attractive to a large enough group of potential policyholders for insurers to incur the costs of developing and marketing the product.

With respect to future research, there is a set of issues that should be addressed with respect to natural-hazard risk. While the use of insurance to handle natural-hazard risk is well understood, its application to the needs of developing countries is an area of increasing focus. As the losses from disasters continue to escalate, additional sources of funding for reconstruction and recovery will be needed. In addition, the reduction of vulnerability to natural-hazard losses is a central policy concern. Insurance provides a tool to both reduce losses by encouraging *ex ante* risk-reducing behavior and by providing post-disaster reconstruction funding. Complex issues related to both the supply and demand of natural hazard catastrophe insurance for the poorest of countries need to be resolved. The use of insurance as a viable policy tool to cope with natural-hazard risk in the developing world is a central theme for economic development policy-makers.

There is a number of open issues that have to be explored in future research in the area of insurance and third-party inspections for accidents

from firms. These include the ability of inspectors to determine how safe a firm actually is, the asymmetry of information between firms, insurers and inspectors and the ability to estimate the risk of chemical accidents and the costs of preventive actions.

In the Kunreuther et al. (2002) model the authors assume that third-party inspections can perfectly distinguish high-risk firms from low-risk ones. It is important to examine how firms would behave if misclassification exists. We also assume an asymmetry of information between firms, regulation agencies and third parties. Only the firms know their own risk levels. But firms sometimes actually do not have a clear idea as to how safe their operations are. How will firms behave when the asymmetry has been removed? Further research on these questions is needed to shed light on the opportunities and challenges of utilizing third-party inspection in concert with insurance, government regulations and/or well-defined standards.

The 11 September 2001 terrorist attack has stimulated considerable interest throughout the world in how we can better manage risk for extreme events such as environmental risks. Insurance is a potentially powerful policy tool for addressing this issue, but as we have shown in this chapter, it needs to be combined with other programs. It is uncertain what types of strategies will emerge in the coming months and years. What is much clearer is that there is a need to rethink the role of the public and private sectors in dealing with risks in dealing with these types of risks.

NOTES

1. Developed by the Geoscience division of Munich Re.
2. A *great natural catastrophe* is defined as one where the affected region is 'distinctly overtaxed, making interregional or international assistance necessary. This is usually the case when thousands of people are killed, hundreds of thousands are made homeless, or when a country suffers substantial economic losses, depending on the economic circumstances generally prevailing in that country' (Munich Re, 2000).
3. A more detailed discussion of insurability conditions and their relationship to environmental and natural hazards protection can be found in Freeman and Kunreuther (1997) and Kunreuther and Roth (1998). Gollier (2000) examines the various factors that may make certain risks uninsurable.
4. For a survey of adverse selection in insurance markets see Dionne and Doherty (1992).
5. This expected loss is calculated as follows: $[50(0.1 \times \$100) + 50(0.3 \times \$100)]/100 = \$20$.
6. See Winter (1992) for a survey of the relevant literature on moral hazard in insurance markets.
7. For more details on deductibles and co-insurance in relation to moral hazard, see Pauly (1968).
8. We are grateful to Henk Folmer for this suggestion.
9. For the correlated risk the expected loss is $0.9 \times \$0 + 0.1 \times \$200 = \$20$. For the independent risk the expected loss is $(0.81 \times \$0) + (0.18 \times \$100) + (0.01 \times \$200) = \$20$.
10. This section is based on Freeman et al. (2001).
11. This section is based on Kunreuther et al. (2002).

12. We could also include indirect impacts in this analysis so that the loss is a function of time (L_t), but this complicates the analysis without changing any of the qualitative results. Indirect impacts include business interruption should the plant be damaged or destroyed, the effect on property values in the community, social and emotional stress to the community as well as long-term impacts on the industry.
13. For example, EPA's Region III has only five auditors for inspecting its many facilities.
14. Of course, if managers of firms are held criminally liable for failure to comply with regulations, there will be added incentives for them to take them seriously.
15. For more details on the role of insurance and inspection in the context of steam boilers, see Er (1996).
16. Many large companies self-insure their workers' compensation program. For an example of regulations related to self-insurance of large employers, see the rules promulgated by the State of Texas (http://wwwprd.twcc.state.tx.us/commission/divisions/selfins.html).
17. State of Delaware, Department of Natural Resources and Environmental Control (DNREC) is the state agency that is the implementing agency for the Extremely Hazardous Substances Risk Management Act.
18. Delaware was selected as one location to carry out experiments because it has had a state regulation for inspecting chemical facilities since 1990. Pennsylvania was selected to conduct third-party audits because state officials in Pennsylvania do not routinely inspect chemical facilities for their risk management programs.
19. For more details on the experiments in Delaware see McNulty et al. (1999). The Pennsylvania project is discussed in US Environmental Protection Agency (2001).
20. See Collins et al. (2002) for a more detailed discussion on how much legal liability third-party auditors would acquire by participating in this program.

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