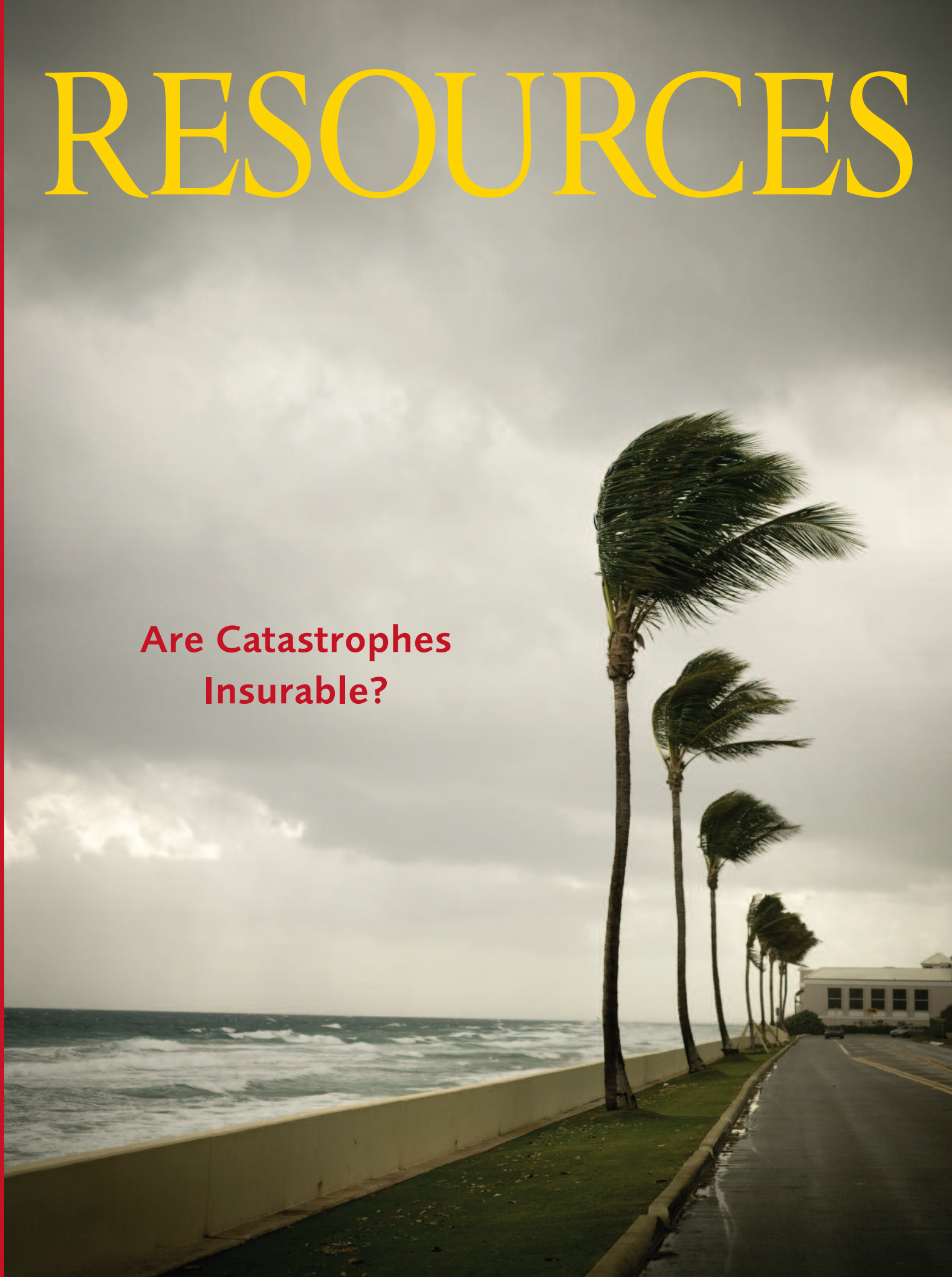
RESOURCES FOR THE FUTURE · RISK · NANOTECHNOLOGY · FOOD SAFETY · SUMMER 2009 · NUMBER 172

RESOURCES



Are Catastrophes Insurable?

WELCOME

The Persistence of Risk

PHILIP R. SHARP
PRESIDENT

Risk and uncertainty will always pose a challenge for policy, obliging us not only to relearn the same lessons over and over, but to learn new ones as well. Grappling with these challenges requires continued research—theoretical advances, sophisticated policy analysis, and policy innovation. For over 50 years, scholars at Resources for the Future have undertaken this important work, and for 50 years, *Resources* has helped communicate that work to a broad audience.

Recently, as I looked over one of the early issues of *Resources*, I noticed a reference to a 1959 report coauthored by the late Gilbert White, who would go on to chair RFF's Board of Directors, on floodplain management. That study noted the failure of developers to account sufficiently for flood risk, and added that the forces influencing development in dangerous areas are "incapable of prolonged pessimism, even where catastrophic loss has been experienced."

Today, this issue remains a pressing one for policymakers. Roger Cooke and Carolyn Kousky address catastrophic events and show why they pose such a difficult challenge, with federal flood insurance providing a cogent example. They show that "fat tails," "microcorrelations," and "tail dependence" are statistical concepts that decisionmakers will ignore at their, and our, peril.

The White study also pointed out that the data available to policymakers on flood risk were "ill-related and confused." Data inadequacies continue to hinder the development of effective policy five decades later. Sandra Hoffmann's contribution reveals how data gaps bedevil our efforts to craft a better food safety system in the United States.

New challenges are emerging as well, such as "nanotech." Terry Davies' article provides a succinct overview of how the uncertainties and potential risks from these emerging technologies are testing the limits of our current regulatory structure. He argues that as the nature of the risks we face evolves, so must our approach to regulating them.

RFF launched *Resources* in 1959, which makes this year its 50th anniversary. It began as a simple newsletter to disseminate "findings and conjectures from recent research into resource and development use" and quickly gained popularity with readers. Over the years it has gone through many changes, but it remains our flagship publication. Today, it is mailed to over 14,000 subscribers in the United States and throughout the world. Many more read it online. Its durability is a testament to the power of RFF's mission—informing policy through the highest-quality research.

RESOURCES

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To learn more about the feature stories in this issue, please enter these links listed below in your web browser or, if reading from our PDF edition, simply select an active link and a new window will open.

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▸ www.rff.org/nanorisk

Attributing U.S. Foodborne Illness to Food Consumption
▸ www.rff.org/foodrisk

Are Catastrophes Insurable?
▸ www.rff.org/insuringcatastrophes

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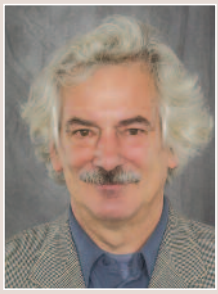

ROGER M. COOKE

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SANDRA A. HOFFMANN

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RFF Vice President for Research and Senior Fellow **Mark A. Cohen** also serves as a professor of management and law at the Owen Graduate School of Management at Vanderbilt University and as an honorary visiting professor in the department of economics at the University of York (UK). Previously, he served as a staff economist at the U.S. Environmental Protection Agency, the U.S. Federal Trade Commission, and the U.S. Sentencing Commission.

Roger M. Cooke is a senior fellow at RFF and the Chauncey Starr Chair in Risk Analysis. He is recognized as one of the world's leading authorities on mathematical modeling of risk and uncertainty and his research has widely influenced risk assessment methodology, particularly in the areas of expert judgment and uncertainty analysis.

RFF Senior Fellow **J. Clarence (Terry) Davies** is a political scientist who, during the last 30 years, has published numerous books and articles about environmental policy. He chaired the National Academy of Sciences Committee on Decision Making for Regulating Chemicals in the Environment and, while serving as a consultant to the President's Advisory Council on Executive Organization, he coauthored the reorganization plan that created the U.S. Environmental Protection Agency (EPA).

Sandra A. Hoffmann, an RFF fellow, focuses her research on the role of economics in regulatory risk analysis. She works on a number of policy issues, including food safety, environmental policy and children's health, environmental health policy in China, and measuring the distributional impacts of environmental policy.

RFF Fellow **Carolyn Kousky** is interested in individual and societal understanding of, preparation for, and response to low-probability, high-consequence events. She has examined how individuals learn about extreme event risk, the demand for natural disaster insurance, and policy responses to a potential change in extreme events with climate change. She is also interested in the use of natural capital to reduce vulnerability to weather-related disasters.

RFF Senior Fellow **Winston Harrington** includes among his research interests urban transportation, motor vehicles and air quality, and problems of estimating the costs of environmental policy. He has worked extensively on the economics of enforcing environmental regulations, the health benefits derived from improved air quality, the costs of waterborne disease outbreaks, endangered species policy, federal rulemaking procedures, and the economics of outdoor recreation.

Juha Siikamäki is an RFF fellow. His work is centered on valuing the environment and evaluating the benefits, costs, and cost-effectiveness of different environmental policy options. He is especially interested in understanding the preferences of consumers, households, and landowners for different policy programs.

BIOGRAPHY LINKS

Detailed profiles of each researcher are available on the RFF website.

Putting a "Collar" on Emissions Permit Prices

RFF Scholars Refine Variant on Safety Valve

Cap-and-trade legislation can reduce carbon emissions with all the efficiency of a classic market. But cap-and-trade also means that the price of emissions permits, like all market prices, will be unpredictable—and that's a cause of real concern both to economists and to politicians. Uncertainty about these prices, and the burden they could put on the economy, has become a huge issue as Congress works on the bill to reduce emissions and slow the warming of the world's climate.

An unexpected spike in permit prices, affecting the cost of all energy derived from fossil fuels, could put companies out of business, destroy jobs, and in general slow economic growth. A sharp drop in permit prices could derail companies' planning and discourage investment in clean energy technologies.

The solution is a collar, a regulatory device that sets a maximum and a minimum price for emissions permits. A "collar" carries with it certain drawbacks, at least in the short run, for it would require the government to issue as many permits as necessary to keep the price from rising above the maximum and set a minimum price for permits. Those possibilities draw objections. On the one hand, issuing more permits would mean allowing the country's carbon emissions to overshoot the annual goal. On the other, a price floor could conversely mean imposing a greater cost on the economy that year than necessary to meet the goal.

But reducing the country's carbon emissions is going to be a long process, and the case for the collar rests on a judgment that long-term stability and predictability in the market for permits are going to be more important than year-to-year deviations in emissions.

Early in the debate over reducing carbon emissions, the difficulty in forecasting the cost of a cap-and-trade program led economists at RFF to design a variation with an upper limit on price. They called it a safety valve. More recently, as governments accumulated actual experience with permit markets—for sulfur dioxide in this country and for carbon dioxide in Europe—Senior Fellows Dallas Burtraw and Karen Palmer saw a need for a lower limit as well. In a ▸ paper early this year they found that, historically, the failure to have a lower price limit has had greater consequences than the absence of an upper limit. They called the "symmetric safety valve" a way to set clear public policy in the presence of uncertainty.

Several months later, another team of researchers, ▸ Senior Fellow Richard Morgenstern and ▸ Fellow Harrison Fell, examined the economic effects of the collar. Most economists, throughout this long debate, have held that a conventional tax on emissions would deliver more reductions at a lower cost than a cap-and-trade system. But a tax is a path that Congress has clearly chosen not to take. The researchers found that, with a collar, a cap-and-trade system could attain a level of efficiency close to that of a tax. In addition, it would provide greater certainty than a tax in the reduction of emissions. ■

News & Notes

New Ideas for Risk Regulation

RFF recently cosponsored the New Ideas for Risk Regulation conference with the Society for Risk Analysis (SRA).

The focus was on regulation of environmental, health, safety, and security risks, and the role of the Office of Information and Regulatory Affairs (OIRA) in the U.S. Office of Management and Budget. Panels covered the role of OIRA domestically and internationally, the regulation of highly uncertain and potentially catastrophic risks, the integration of risk assessment and risk management, the role of cost-benefit analysis, the assessment of equity, and the estimation of preferences.

Sally Katzen, a former OIRA administrator and member of the Obama transition team, and fomer RFF President Paul Portney were the plenary speakers. Portney's talk examined whether cost-benefit analysis and common sense are "friends or foes." He said that in a fundamental sense they are friends—a systematic evaluation of pros and cons is a necessary ingredient of good decisionmaking. But he added that there are some cases where cost–benefit analysis and common sense appear to be at odds.

The conference video, as well as downloadable copies of the slides and papers from many sessions, are posted on the RFF website (www.rff.org/rff-sra). Articles based on selected conference presentations are also planned to be published in *Risk Analysis* in 2010.

Every summer, interns come from around the world to work with the RFF research staff. Pictured from left (top row): Daniel Marbury, Brent Wanner, Gabrielle Wong-Parodi, Noah Kaufman, RFF President Phil Sharp, Gennerre Crockett, Brent Arnold, Rob Stewart, Jane Zhao, Rebecca Butler; (bottom row): Ashley Schoettle, Erin Mastrangelo, William Harder, Kate Farley, Leah Stokes, Ewan Robinson, Aditi Vasan. Not pictured: Jesse Burkhardt, Steve Hamrick, Mohamed Kamara, Josephine Nalule, Jess Wilhelm (this year's Walter O. Spofford, Jr., Intern).

IN MEMORIAM

Francis T. Christy, Jr. (1926–2009)

Francis T. Christy, Jr., a prominent RFF researcher during the organization's first three decades, recently passed away after a prolonged illness. He was a recognized authority on international fish conservation policies and was among the first to warn that commercial overfishing could deplete marine habitats around the world.

Christy held an economics Ph.D. from the University of Michigan and coauthored (with Neal Potter) *Trends in Natural Resource Commodities* (1962), which became a major statistical building block for several important RFF studies dating from that period. Turning his focus increasingly to global marine problems and policy challenges, he (with coauthor Anthony Scott) wrote the 1965 RFF volume *The Common Wealth in Ocean Fisheries.* In 1973, he published an occasional paper, entitled "Fishermen's Quotas: A Tentative Suggestion for Domestic Management," which described for the first time the use of fishing quotas to address the all-too-common occurrence of "too many boats, chasing too few fish."

"Francis Christy provided the intellectual foundations for one of the most significant innovations in fisheries management and influenced a generation of marine resource economists in the process," said RFF University Fellow James Sanchirico. "Today fishing quotas are in use throughout the world and appear to have growing momentum in the United States as well."

After leaving RFF in 1979, Christy spent the major part of his ensuing professional career with the Food and Agriculture Organisation of the United Nations.His work on international fisheries management heavily influenced the 1982 UN Law of the Sea treaty.

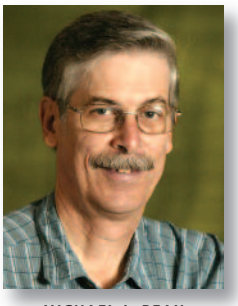
■ ■

Members of RFF Family Join Obama Administration in Policy Roles

Former RFF Senior Fellow **Richard G. Newell** has been appointed by President Obama as administrator of the federal Energy Information Administration (EIA), part of the Department of Energy. Newell joined RFF in 1997, where he focused on energy and climate policy, transportation, and air quality. He replaces acting administrator Howard Gruenspecht, also a former RFF senior researcher.

RICHARD G. NEWELL

Michael J. Bean, a former RFF Board member, has joined the Department of the Interior as senior adviser on endangered species law and cooperative conservation. He was with the Environmental Defense Fund for many years, most recently as chair of the wildlife program there.



MICHAEL J. BEAN

Michael Taylor, a former RFF senior fellow and research professor at George Washington University's School of Public Health and Health Services, is going to the Food and Drug Administration to serve as senior adviser to the commissioner for food safety issues. There he will identify capacity needs and regulatory priorities, develop agency budget requests, and plan implementation of new food safety legislation. ■

MICHAEL TAYLOR

Double the Fun? Outdoor Recreation Up Twofold in 50 Years

Time spent on recreation outdoors by Americans has more than doubled since the 1960s, according to a new study by RFF Fellow Juha Siikamäki, who finds nearly 20 percent of the U.S. population is currently active in outdoor pursuits on any given day. The findings are included in a new discussion paper, "Use of Time for Outdoor Recreation in the United States, 1965–2007."

The big jump from the 1960s was largely driven by an overall increase in the percentage of the population participating in outdoor recreation, which according to Siikamäki has approximately doubled since the 1960s. Today Americans spend, on average, around two hours per person per week in outdoor recreation and physically active sports, a drop since the 1990s, when the number was slightly higher—2.68 hours per week—and people had more leisure time. This declining trend has not continued in recent years, he notes.

In general, people going to the great outdoors tend to be male, younger, and have more years of education than the overall population, Siikamäki notes. Gender differences are particularly salient: compared to women, men participate more often and spend more time on outdoor recreation, up to one and half times more, although this gap has somewhat closed during the last two decades (see figure).

So what explains this difference? Siikamäki says other demographic factors are certainly influential: households with kids are less likely to participate than those without, although those that do spend the same amount of time. Individuals who work full-time are less likely to make it outdoors but spend even more time when they go. Education is also a strong determinant, as is the amount of available leisure time.

The differences across age groups are more idiosyncratic than those based on gender. By and large, young adults (under 35 years old) spend more time and participate more frequently in outdoor recreation than other adult populations. Interestingly, the amount of leisure time spent by the under-35-year-old population has remained relatively constant since 1965, yet this age group has noticeably increased involvement in outdoor recreation and roughly tripled the percentage of the total amount of leisure allocated toward outdoor recreation.

Another major change since the 1960s and 1970s has been the dramatic increase in the amount of leisure for people over 60 years old. Though in percentage terms individuals in this age group use less of their available leisure in outdoor recreation than in 1965, the absolute number of hours per person they spend on outdoor recreation has remained roughly constant.

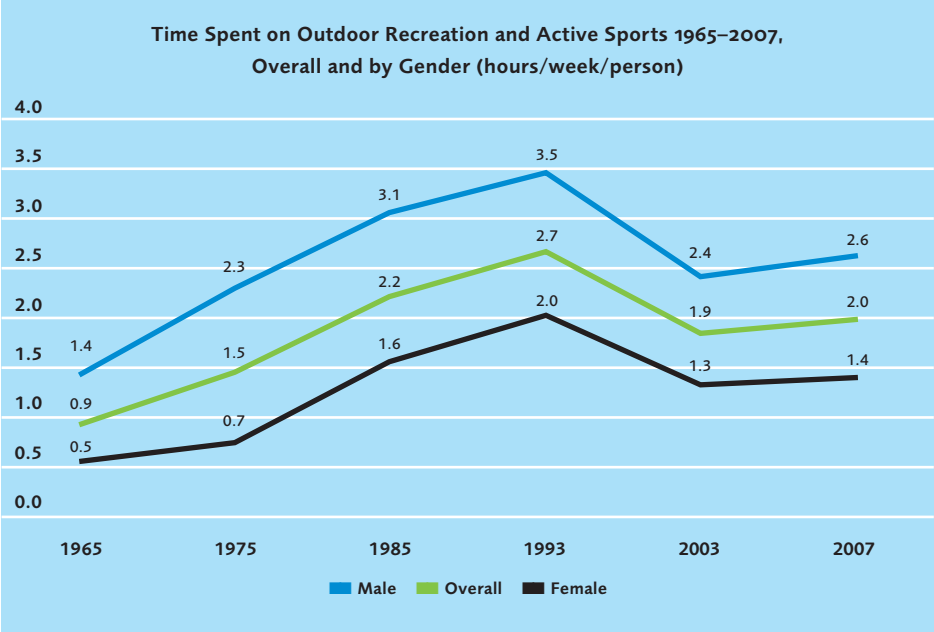
Responding to changing trends

It's important to assess the extent to which demographic differences in outdoor recreation have resulted from outdoor recreation policy versus simple differences in preference among demographic groups, according to Siikamäki.

Improving access to public parks closer to urban and suburban areas, as well as crafting policies to address demographic groups that currently are relatively passive, could encourage outdoor recreation among the broader population. The nature of recreation is also changing as new popular options such as mountain biking, bird-watching, rock climbing, and motorized recreation, including snowmobiling and driving off-road vehicles, supplement traditional activities such as hiking, fishing, hunting, and camping. Siikamäki also notes that more needs to be known about the adolescent population, which according to popular claims is growing apart from contact with nature and nature-based activities.

"Much of the policy and physical infrastructure for outdoor recreation was developed decades ago," he says, "and it is vital to evaluate whether this infrastructure still meets the demands of today and the future. Today's society also presents new emerging policy problems, such as obesity and other public health issues associated with the physical fitness of individuals." ■

This article is based on a longer RFF discussion paper prepared for the Outdoor Resources Review Group (www.rff.org/orrg) Resources for the Future Background Study. The discussion paper can be found at ▸ www.rff.org/RFF/Documents/RFF-DP-09-18.pdf.



RFF POLICY COMMENTARY

How to Deter Oil Spills

Mark A. Cohen

A single pint of oil can spread into a film covering an acre of water surface area, degrading the environment and ultimately threatening human health. To encourage compliance with laws prohibiting the discharge of oil, government agencies can hike the penalty for a violation or increase monitoring activities to raise the likelihood that an offender will be caught and punished.

In theory, less monitoring coupled with higher penalties is always beneficial. Taking economist Gary Becker's "crime and punishment" model to its logical conclusion, the optimal penalty is arbitrarily high and the optimal expenditure on monitoring approaches zero. In reality, however, such a policy would bankrupt any firm that spilled even a few pints and thus stifle commerce: who would take such a risk?

Consequently, we need a policy that includes a significant amount of monitoring and well-designed penalties for noncompliance. EPA and the Coast Guard both have enforcement powers and conduct monitoring to prevent oil spills. Should a spill occur, U.S. law also requires that the responsible firm report it and clean it up: EPA and the Coast Guard may assess administrative penalties and require remedial actions, and courts may impose civil or even criminal sanctions.

Much has changed in the past two decades. The 1990 Oil Pollution Act (OPA), passed a year after the *Exxon Valdez* spilled more than 10 million gallons of crude into Prince William Sound, states that a company cannot ship oil into the United States until it presents an acceptable plan to prevent spills and a detailed containment and cleanup plan in case of an oil spill. Since then, the number and volume of spills in U.S. waters have declined considerably, primarily due to the introduction of double-hulled vessels, which have prevented many of the largest spills. For example, the Coast Guard reports the number of spills to have dropped from about 700 to 400 annually, and the volume of oil spilled reduced from about 5 million gallons to 600,000 gallons annually, since OPA was enacted.

But those numbers do not tell the whole story. Not all spills are large and many are not even accidental: vessel operators have been known to clean their bilges out near a port in order to save money, and some spills simply occur through faulty or negligent transfer operations.

Aside from technological mandates such as double-hulled tankers, how effective are the various approaches—monitoring, enforcement, penalties—in deterring oil spills, and what is the best mix?

Assessing data on compliance and enforcement is not an easy task. A reported increase in enforcement activities might indicate more frequent spills, but it could also reflect better monitoring and detection, or more vigorous prosecution. Empirical studies must be carefully designed to sort out the effect that these variables have on actual spill frequency versus spill detection.

Monitoring oil transfer operations has been found effective in reducing oil spill volumes: the crew of a tanker apparently takes more care when the Coast Guard is watching. Such monitoring might also have a general deterrent effect on all vessels that transfer oil. If captains believe they might be monitored in the future, they probably train their crews and check their equipment more thoroughly, even if they are never actually monitored. Random port patrols looking for oil sheens have a similar influence because they raise the overall probability of detection. However, increased compliance inspections themselves have not been found to be as effective as the other two mechanisms.

Alternative Approaches

Because government monitoring is expensive, three alternatives have been tested: targeted monitoring for vessels thought likely to be out of compliance or likely to spill oil; differential penalties based on prior compliance history, with higher penalties for frequent violators; and mandatory self-reporting, with higher penalties for vessel operators who do not voluntarily report their spills.

Targeted monitoring. In the early 1980s, the Coast Guard began classifying ships as low risk (to be monitored only occasionally) and high risk (always monitored). This two-tiered enforcement policy has been found to be effective in reducing the cost of enforcement without having a negative effect on the environment.

Differential penalties. A 2000 study by Weber and Crew found penalties ranging from $.003 to $73.35 per liter, and estimated that increasing the fine for large spills from $1 to $2 a gallon decreased spillage by 50 percent. They concluded that the current penalty policy—relatively high per-gallon fines for small spills and very low per-gallon fines for large spills—undermined deterrence. Their results parallel my 1986 study: that the Coast Guard's statutory maximum penalty of $5,000 was too small relative to the optimal penalty required. Under OPA, the potential penalties have considerably increased, up to $1,000 per barrel of oil discharged.

Self-reporting. To increase deterrence and lower the cost of government monitoring, vessel operators are told they must report any spill, and if the government detects a spill that was not voluntarily reported, the penalty is higher and may include a criminal sanction. Firms found to be out of compliance are more likely to self-report violations in subsequent periods. This suggests that firms try to regain credibility with the government so that they will be taken off a target list.

Firm reputation. Information that a firm has been sanctioned for violating environmental laws may be of interest to shareholders or lenders if the monetary sanction reduces the expected value of the firm and therefore its

share price or bond rating. It may also give lenders and insurers pause about risking more capital on that particular firm. Other costs might include future debarment from government contracts, targeted enforcement by EPA, and lost sales to green consumers. Several studies looking at bad environmental news, such as oil or chemical spills or the announcement of civil enforcement actions, have demonstrated a negative stock price effect. However, the evidence is mixed as to whether this price effect simply reflects the expected cost of penalties and cleanup as opposed to any additional reputation penalty.

Policy Implications

Despite OPA's success in reducing spills, costs associated with oil spills are still significant. A recent Coast Guard study estimated the total cost of removal and damages from oil spilled since 1990 to be $1.5 billion. If the government's goal is to improve the environment at the least cost to society, then firms that are the most likely to cause significant harm need to be identified along with those most likely to be responsive to enforcement activities as well as compliance assistance. This kind of empirical evidence can help government agencies plan targeted enforcement measures. Additional evidence on the cost of enforcement and compliance must be gathered, however, to conduct a cost–benefit analysis.

In terms of sanctions, the evidence to date shows little deterrent effect from fines that are only a few thousand dollars. To have any real effect, significantly larger fines and/or targeting responsible individuals instead of firms may be appropriate.

Finally, community pressure and social norms can be important factors in compliance. External market pressures may exert some influence on firm behavior and help prevent oil spills from occurring. Being known as a polluter may induce firms to take precautions, lest consumers and shareholders exact their own form of punishment. ■

▸ Further readings and additional commentaries are available at www.rff.org/weeklycommentary.

RFF Launches Climate Policy Blog

RFF has updated ▸ Weathervane as a blog on climate policy. Weathervane was originally created in 1997 and was designed to advance and inform debates surrounding the environmental and economic aspects of climate change. Before the era of blogs, it fostered an informed discussion of climate policy and developed a reputation for producing thoughtful, high-quality analysis. At the time, it was unique and became a valuable resource for those interested in climate policy.

Although the world has changed quite a bit since its inception, there is still a need for a nonpartisan, dispassionate forum where essential elements of climate policy can be discussed in an in-depth and accessible way. Weathervane will feature observations from RFF scholars on current climate policy developments, discussions of current RFF research, and contributions from distinguished experts. (See Winston Harrington's post below on the "cash-for-clunkers" program.)

Weathervane is an initiative of RFF's Climate Policy Program, which provides a framework for policymakers and stakeholders to better understand and address key issues related to climate change policy. Weathervane takes advantage of new communication technologies: you can post comments online, follow it on Twitter, and become a fan on Facebook. ■

A RECENT WEATHERVANE POST:

A Closer Look at "Cash for Clunkers"

Recent legislation allows auto dealers to provide vouchers to consumers toward the replacement of their existing vehicles with new vehicles getting better fuel economy. The vouchers are worth $3,500 to $4,500, depending on the type of vehicle being replaced, its fuel economy, and the fuel economy of the new vehicle.

This program is similar in some ways to the vehicle retirement programs that have been used by many states and local areas with the goal of reducing emissions of the local air pollutants hydrocarbons and nitrogen oxides. These earlier programs were reasonably cost effective (at least compared to many of the local alternatives available), but they really did not generate large emissions reductions. Furthermore, the programs that worked best were of necessity short term. In a continuous program there were some incentive problems that would be hard to overcome. . . .

The cash-for-clunkers program avoids most of these incentive problems, fortunately. However, it cannot avoid all of them. Like most subsidy programs that try to change behavior, it will tend to reward those who were going to do the right thing anyway, in this case buy an energy-efficient vehicle.

Many households now own at least three vehicles, and often the third or fourth vehicles are not driven very much. That ancient gas-guzzler that's just sitting in your driveway might be an attractive way of knocking a few hundred dollars off the cost of a new car. And even if you're not in the market for a new car, you might profit from selling it to someone who is. ■

—Winston Harrington

A Brief History of Quantitative Risk Assessment

ROGER M. COOKE

In ancient Egypt, the Nile River could yield its bounteous flood for 30 years in succession, and then have two dry years in which all harvests failed. If the ancient Egyptians knew in advance exactly when the Nile would fail to flood, they would not have needed scribes, taxation, writing, calculations, surveying, geometry, or astronomy. Civilization owes much to risk. Without uncertainty there is no risk, only adversity.

Risk is a wily adversary, obliging us to relearn the same lessons over and over. Why do we build flimsy upscale houses in the paths of hurricanes? Why does the lure of short-term gain foil the best minds in business and finance? Why do we bet the farm on "slam dunk" assessments, despite evidence to the contrary? In short, why don't we learn to manage risk and uncertainty?

For the ancient Egyptians, it was a matter of detailed recordkeeping and building storehouses of grain to prepare against drought. In modern times, we have new tools and approaches for measuring and quantifying risk, as this brief history of modern quantitative risk analysis outlines. In the interest of brevity, we'll focus here on the three dominant "actors."

Aerospace

A systematic concern with a new form of quantitative risk assessment called probabilistic risk assessment (PRA) began in the aerospace sector following the fire of the 1967 Apollo flight test in which three astronauts were killed. Prior to the Apollo accident, NASA relied on its contractors to apply good engineering practices to provide quality assurance and quality control. NASA's Office of Manned Space Flight subsequently initiated the development of quantitative safety goals in 1969, but they were not adopted. The reason given at the time was that managers would not appreciate the uncertainty in risk calculations.

Following the inquiry into the Challenger accident of January 1986, we learned that distrust of reassuring risk numbers was not the only reason that PRA was abandoned. Rather, initial estimates of catastrophic failure probabilities were so high that their publication would have threatened the political viability of the entire space program. Since the shuttle accident, NASA has instituted quantitative risk analysis programs to support safety during the design and operations phases of manned space travel.

Nuclear Power

Throughout the 1950s, following President Eisenhower's "Atoms for Peace" program, the American Atomic Energy Commission pursued a philosophy of risk management based on the concept of a "maximum credible accident." Because credible accidents were covered by plant design, residual risk was estimated by studying the hypothetical consequences of "incredible accidents." An early study released in 1957 focused on three scenarios of radioactive releases from a 200-megawatt nuclear power plant operating 30 miles from a large population center. Regarding the probability of such releases, the study concluded that no one knows how or when we will ever know the exact magnitude of this low probability.

Successive design improvements were intended to reduce the probability of a catastrophic release of the reactor core inventory. Such improvements could have no visible impact on the risk as studied with the above methods. On the other hand, plans were being drawn for reactors in the 1,000-megawatt

range located close to population centers, developments that would certainly have had a negative impact on the consequences of an incredible accident.

The desire to quantify and evaluate the effects of these improvements led to the introduction of PRA. While the earlier studies had dealt with uncertainty by making conservative assumptions, the goal now was to provide a *realistic* assessment of risk, which necessarily involved an assessment of the uncertainty in the risk calculation. Basic PRA methods that were developed in the aerospace program in the 1960s found their first full-scale application, including accident consequence analysis and uncertainty analysis, in the 1975 *Reactor Safety Study,* published by the Nuclear Regulatory Commission (NRC).

The study caused considerable commotion in the scientific community, so much so that Congress created an independent panel of experts to review its achievements and limitations. The panel concluded that the uncertainties had been "greatly understated," leading to the study's withdrawal.

Shortly after the Three Mile Island accident, a new generation of PRAs appeared in which some of the methodological defects of the *Reactor Safety Study* were avoided. The NRC released the *Fault Tree Handbook* in 1981 and the *PRA Procedures Guide* in 1983, which shored up and standardized much of the risk assessment methodology. An authoritative review of PRAs conducted after Three Mile Island noted the necessity to model uncertainties properly in order to use PRAs as a management tool.

A 1991 set of NRC studies known as NUREG 1150 used structured expert judgment to quantify uncertainty and set new standards for uncertainty analysis, in particular with regard to expert elicitation. Next came a U.S.–European program for quantifying uncertainty in accident consequences models. Expert judgment methods, as well as screening and sensitivity analysis, were further elaborated. European studies building off this work apply uncertainty analysis to European consequence models and provide extensive guidance on identifying important variables; selecting, interviewing, and combining experts; propagating uncertainty; inferring distributions on model parameters; and communicating results.

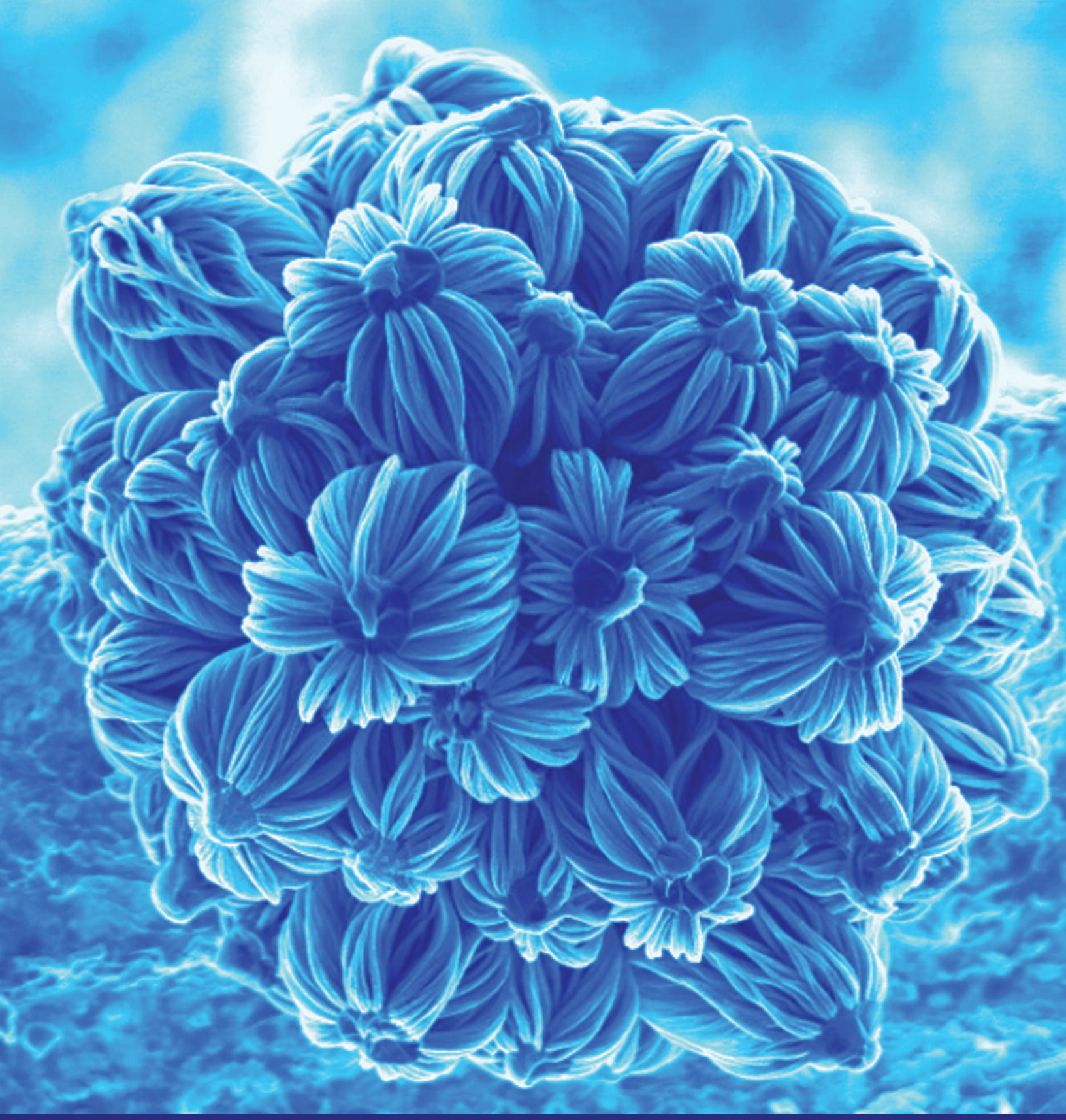
National Research Council

The National Research Council has been a persistent voice in urging the government to enhance its risk assessment methodology. A 1989 report entitled *Improving Risk Communication* inveighed minimizing the existence of uncertainty and noted the importance of considering the distribution of exposure and sensitivities in a population. The issue of uncertainty was a clear concern in the National Research Council reports on human exposure assessment for airborne pollutants and ecological risk assessment. The 1994 landmark study *Science and Judgment* gathered many of these themes in a plea for quantitative uncertainty analysis as *"the only way to combat the 'false sense of certainty,' which is caused by a refusal to acknowledge and (attempt to) quantify the uncertainty in risk predictions."*

The 2003 National Academy of Sciences report *Estimating the Public Health Benefits of Proposed Air Pollution Regulations* identified three barriers to the acceptance of recent EPA health benefit analyses. These are: large amounts of uncertainty inherent in such analyses, EPA's manner of dealing with them, and the fact that *"projected health benefits are often reported as absolute numbers of avoided death or adverse health outcomes."*

The Office of Management and Budget released a draft bulletin proposing technical guidance for risk assessments produced by the federal government. A National Research Council review found many shortfalls in this proposal and recommend that it be retracted. A revision is currently in preparation. The latest National Research Council publication attempts to advance risk assessment at EPA by harmonizing a diversity of approaches and methods.

The amateurism and shortsightedness displayed during Hurricane Katrina, and still evident in the aftermath, might suggest that 5,000 years of civilization have taught us nothing about risk. Not true—we have learned a great deal about risk, as the articles in this special issue attest. However, the more we learn, the more complex are the assets we put at risk. The question is not are we learning, but are we learning fast enough? Does our understanding of risk keep pace with the risks we ourselves create? ■



This 3-D nanostructure was grown by controlled nucleation of silicon carbide nanowires on liquid metal catalyst particles. As the growth proceeds, individual nanowires, about one-thousandth the diameter of a human hair, knit together to form 3-D structures. Researchers are investigating possible applications for these new materials, such as water-repellent coatings and as a base for a new type of solar cell. (Courtesy: National Science Foundation. ©Ghim Wei Ho and Professor Mark Welland, University of Cambridge.)

Nanotechnology and Risk

J. Clarence (Terry) Davies

Nanotechnology is the science and application of manipulating matter at the scale of individual atoms and molecules. All natural processes, from the growth of human embryos to plant photosynthesis, operate in this way, but only recently have we developed the tools that allow us to build and analyze things at the molecular level. For the first time in human history, we are close to being able to manipulate the basic forms of all things, living and inanimate, taking them apart and putting them together in almost any way the mind can imagine. The world of the future will be defined by how we use this mastery.

The benefits of nanotechnology, both current and future, are hard to exaggerate. Nanotechnology is used now to make car bodies stronger and lighter, to make batteries and solar panels more efficient, to make glass that never needs cleaning and neckties that are stainproof, and to deliver medicines to individual cells in the body. In the future, assuming that the technology is not impeded by public opposition, "nano" will bring us water desalination at a fraction of the current cost, materials that can make objects invisible, revolutionary new types of computers, and medicines that will cure many major diseases.

The technology also has potential risks, and no nation—including the United States—has the oversight policies and institutions needed to deal with these risks.

Ignorance Doesn't Lead to Bliss

We actually know very little about the risks of nanotechnology. To date, there are no documented instances of anyone being harmed by the technology or its applications. However, we know enough about the technology and have enough experience with other technologies to confidently predict that some kinds of problems will arise and that other kinds of problems should be guarded against. Here I will discuss three facets of risk: risk to human health and the natural environment, concerns about social values, and the importance of perceived risk.

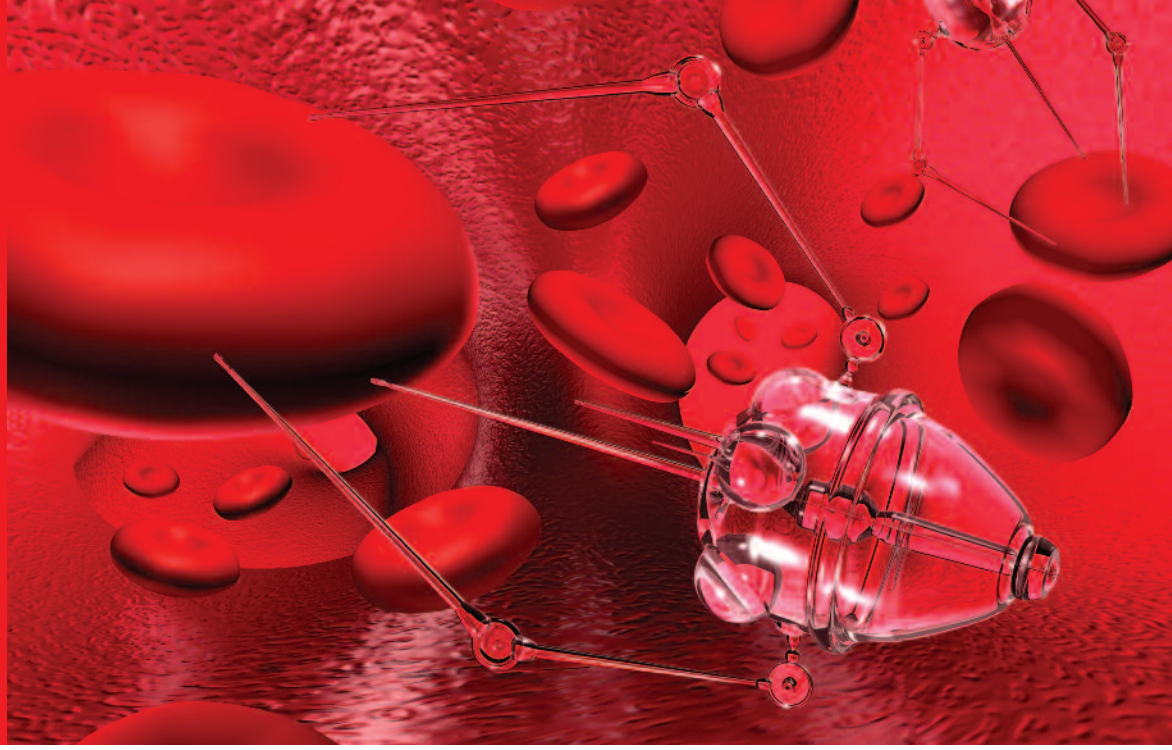
Risks to health and environment

There is a dearth of information about the health and environmental risks of nanomaterials because the technology is relatively new and insufficient resources have been devoted to understanding its risks. Of the $1.5 billion the U.S. government is spending annually on nano research and development, less than 3 percent is for research to identify health and environmental risks, and even this small amount is not being spent in accordance with any well-formulated strategy.

But there are several reasons to be concerned about nano's health and environmental effects. First, nanomaterials commonly behave differently from materials of ordinary size—often following different laws of physics, chemistry, and biology. For example, aluminum is harmless when used in soft drink cans, but nanoscale aluminum is so explosive that it is being considered as bomb-making material by the military. The differences between nanomaterials and ordinary materials mean that much of our existing knowledge about risks is not applicable to nanotechnology.

Second, one of the defining characteristics of nanomaterials is their very large surface area relative to their mass. It is on the surface of materials that chemical and biological reactions take place, so one would expect nanomaterials to be much more reactive than bulk materials. This is an advantage in many nano applications but can also be a potential hazard.

Third, the small size of nanomaterials means that they can get to places ordinary materials cannot. For example, there is some evidence that nanomaterials can penetrate the blood–brain barrier. This could be an advantage for delivering medications but could be



Translucent medical nanobots fixing blood cells. Researchers are working on medical nanotechnology that can act on a cellular level to help fight diseases, repair organs, and collect data such as red and white blood cell counts or blood sugar levels. Nanoparticles are already helping to deliver drugs to targeted tissues within the body.

a serious danger if certain types of materials were inhaled or ingested.

A fourth reason for concern is that, based on past experience, it would be extraordinary if nanomaterials did not pose potential health and environmental problems. Our experience with bulk chemicals has taught us the necessity of oversight, and nanomaterials are, indeed, chemicals.

The results of nanomaterial toxicity tests using laboratory animals have been inconclusive to date but give cause for concern. They show that even small differences in the characteristics of a nanomaterial, such as its shape or the electrical charge at its surface, can make a big difference in its chemical and biological behavior. So, testing done on substance "A" may not identify the risks of substance "B" even though the two substances seem almost identical. The most worrisome test results have shown that when certain types of carbon nanotubes (a very common form of nanomaterial) are inhaled by laboratory animals, they produce the same type of precancerous lesions as asbestos. Other tests have indicated that some nanomaterials may damage DNA or certain types of cells. As more testing is done, these results will become more or less certain and other effects are likely to be identified.

Social risks

If one defines risk as the possibility of an adverse consequence, health and environmental risks are not the only kinds of risks a technology may pose. People are often concerned about a technology being used in a way that conflicts with some deeply held value, and some uses of nano may create such conflict.

A 2004 study by Grove-White and others compared the issues in the controversy over biotechnology to those that might be expected in relation to nanotechnology. Their findings showed that there are potentially strong similarities, including concerns about: "global drives towards new forms of proprietary knowledge; shifting patterns of ownership and control in the food chain; issues of corporate responsibility and corporate closeness to governments; intensifying relationships of science and scientists to the worlds of power and commerce; unease about hubristic approaches to limits in human understanding; and conflicting interpretations of what might be meant by sustainable development." As the authors point out, these kinds of concerns cannot be accommodated within a framework of risk assessment of individual nanotechnology products.

Nano is also likely to raise a number of ethical questions that cannot be addressed within the usual risk assessment framework. If nanotechnology can be used to improve the functioning of the human brain, should it be used that way? And, if so, for whose brains? If nanoscale materials are incorporated in foods to improve nutrition, shelf life, or taste, should the food have to be labeled to show that nano has been used? If synthetic biology, which is becoming increasingly merged with nanotechnology, can create new life forms, should it be allowed to do so? (Synthetic biology is a new area of biological research that combines science and engineering in order to design and build, or "synthesize," novel biological functions and systems.) These and many other issues likely to be raised by nanotechnology in the not-too-distant future may pose potential risks to values.

Perceived risk

The greatest threat to the development and application of nano may not be any actual documented risk but rather a perception that the technology is risky and dangerous. Such perceptions are pro-

duced by an amalgam of real risks, people's cultural orientation, information disseminated about the technology, perceptions of the adequacy of safeguards against risk, and probably other factors.

Because nanotechnology is new, invisible, and hard to explain in ordinary language, it lends itself to nonrational opinions. Polls show a large majority of people have little or no knowledge of the technology, but this is no bar to many of those polled having strong opinions on the subject. The experts, seeking to gain support for the technology or at least foster a more elevated debate about it, have supported public education about nano. They have been cheered by studies showing that support for nano correlates with knowledge about the technology. However, Dan Kahan and others have shown that the direction of causation is probably the reverse of what has been assumed. People who are culturally inclined to support new technologies are also more inclined to learn about the technologies. In experiments, providing added information about nanotechnology to people whose cultural views were mistrustful of new technologies left the people more mistrustful of nano even though the information was quite balanced.

It may be tempting to dismiss views based on a lack of information or on misinformation. However, perceived risk is a real factor in people's behavior. If we want them to buy products containing nanomaterials or not support bans on nanotechnology research, we need to understand that perceived risks are at least as important as "real" risks.

Nano Oversight Needs

The U.S. regulatory system is not prepared to deal with nanotechnology or the other technological advances that lie ahead. In the near term, many of the changes needed to deal with nanotechnology are the same as those needed to remake the currently dysfunctional regulatory system. All four of the major environmental health and safety regulatory agencies—the EPA, Food and Drug Administration (FDA), Occupational Safety and Health Administration (OSHA), and Consumer Product Safety Commission (CPSC)—are hobbled by antiquated and perverse laws and totally inadequate resources. The agencies need more money and more personnel with relevant expertise. And there needs to be a significant increase in research on the risks posed by nanomaterials.

Under their existing authority, the regulatory agencies could take numerous steps to improve oversight of nano products and materials. However, to provide even minimally adequate oversight, legislative action is essential. The Toxic Substances Control Act (TSCA) is the only law that can regulate nanomaterials generally. It is a deeply flawed act that needs major overhauling, not just for nano but for any type of chemical. The Federal Food, Drug, and Cosmetic Act regulates a variety of important uses of nanomaterials, such as nano drugs and the use of nanomaterials in food. However, it contains language that prevents oversight of two uses that involve high human exposure to nanomaterials—dietary supplements (vitamin pills, herbal remedies, and the like) and cosmetics.

In the longer term, the revolutionary scientific and technological innovations that are on the horizon will require totally different ways of dealing with potential risk. The future will be characterized by rapid scientific advancement, rapid utilization of science, frequent product changes, technical complexity, and a variety of novel ethical, social, health, and environmental challenges. A regulatory system that takes two years to issue a rule cannot deal with an economy where product lines typically change every six months. A regulatory law focused on types of chemicals cannot deal with something like nanomaterials where often the same chemical substance can have radically different effects depending on small changes in its shape or in the method by which it is manufactured.

Many longer-term changes are needed. One of the most important would be the creation of a new Department of Environmental and Consumer Protection, which would incorporate six existing agencies—EPA, CPSC, OSHA, the National Oceanic and Atmospheric Agency, the U.S. Geological Survey, and the National Institute of Occupational Safety and Health. This new meta-agency would focus on science and monitoring although it would have a strong oversight component. It would foster more integrated approaches, requiring new legislation. There is a clear need for a more integrated law focusing on dangerous products that would supersede such existing laws as TSCA and the Consumer Product Safety Act.

The United States is not prepared to deal with the challenges posed by 21st-century science and technology. Thinking and discussion about new approaches should start now. The future context for dealing with risk will be unlike anything we have known, and the policies of the past will not provide the protection we need. ■

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Attributing Illness to Foo

Sandra A. Hoffmann

Over the past three years, *USA Today* has run a major story on a food safety problem almost every month. U.S. consumers may be a bit shell-shocked by the barrage of headlines warning of foodborne pathogens (disease-causing organisms) or harmful chemicals. American consumers—as well as those in the agriculture and food-processing industries—are undoubtedly asking, what next?

Unfortunately, with foodborne illness it is even difficult to say which foods have been the biggest problems in the past. The reasons are actually as simple as these: the evidence gets eaten or thrown out; illness may follow food consumption by days or even years; and, human memory, particularly when trying to remember what one had for dinner even three days ago, is frail. Just as unfortunately, it is important to know which foods caused the most illnesses in the past in order to reduce illness in the future.

Compelling, substantive reasons exist—for all parties involved—to want to invest time and effort in developing information on the sources of foodborne illness. Consumers need to know how to handle foods safely and be able to recognize the relative riskiness of particular foods to guide their purchase decisions. Producers would like to know whether the types of foods they produce are likely to be the next story on the front page of the *New York Times* so they can develop strategies to avoid potential financial risk. Supply-chain managers want to know about the relative riskiness of the different sources of a product so they can appropriately weigh the costs and benefits of each source. Governments want to know about the relative riskiness of foods to effectively design laws and target efforts to protect the public from health risks.

There are also important procedural reasons for wanting quantitative data on the sources of foodborne illness—reasons related to ensuring that regulations are actually needed and do not unfairly burden trade. Both industry and consumers are often concerned about special interests having undue influence on government agencies or about government agencies writing rules that favor one firm over another.

Government agencies in the United States and abroad rely on formal risk assessment as the primary means of understanding how health risks arise in the food supply. Risk assessment is a process of quantifying and modeling the pathway from contamination through exposure to health outcomes. It typically relies on dose-response relationships to predict illnesses or deaths. Estimating a pathogen dose-response relationship is difficult, however, because pathogens tend to be species specific and human testing is considered to be unethical. An alternative is to estimate disease incidence from epidemiological data and then attribute it back to the source of infection—in other words, a food attribution estimate.

In the Absence of Hard Data...

Uncertainty abounds in estimates of the number of cases of foodborne illness each year. Health statistics depend heavily on reporting by physicians and medical laboratories, but most cases of foodborne

U.S. Foodborne d Consumption

illness are probably mild and never show up at a doctor's office. When someone with foodborne illness does seek medical attention, the physician or medical laboratory may not report the illness to public health authorities and, if it is reported, it may be identified only as a case of infectious disease. In fact, the Centers for Disease Control scientists estimate that for many pathogens, only 1 in 38 cases of foodborne illness are reported.

Even greater uncertainty exists about the food sources of foodborne illness. Food safety managers and public health officials need to know which pathogens either in or on which foods are making people sick. Physicians can determine which pathogen made a patient sick by ordering a laboratory test, but that typically does not occur because such tests are more useful for public health surveillance than for patient care. Even if a physician suspects that an illness is foodborne, it will typically be difficult to pinpoint the cause. Individuals' ability to recall what they ate is notoriously poor. Often, a few days may pass between infection and illness, and then it is a guess as to which food was actually associated with the illness. Again, there is usually no clinical reason to investigate the matter further.

In response to these reporting problems, the Centers for Disease Control and Prevention (CDC) and state public health surveillance authorities have developed three major foodborne illness surveillance programs: OutbreakNet, PulseNet, and FoodBorne Diseases Active Surveillance Network (FoodNet). Although these systems provide helpful information about the sources of foodborne illness, further work is needed to make them truly useful for food attribution in policy analysis.

A number of efforts are under way within federal agencies to adapt this data or to create new data to meet the need for attribution estimates. Most of these efforts are targeted at specific regulatory needs. For example, the Food Safety Inspection Service is working on attribution of *Salmonellosis* to food products under its jurisdiction, using a sampling and genetic subtyping protocol developed in Denmark. The CDC is working on two food-system-wide approaches, one based on outbreak case data that could be updated in real time, and another that relies on a blend of outbreak and case-control study data. Microbiologists also continue to work on the problem of developing predictive dose-response models for human foodborne pathogens.

In the absence of hard data, judgment-based estimates are also used. Usually, this is done informally. Current estimates attributing the incidence of foodborne illness to specific pathogens rely heavily on the expert judgments of a group of researchers at the CDC to fill gaps in the literature. More formal methods are being developed; for example, evidence-based medicine has developed a set of criteria for evaluating studies through systematic literature reviews that are used to identify best clinical practices. Risk analysis in environmental and safety policy has long relied on structured analysis or elicitations of expert judgment for subjective estimates of missing parameter values.

It doesn't take much to have a big public health impact: four food groups—produce, seafood, poultry, and ready-to-eat meat—and just three pathogens account for a sizable majority of all foodborne illnesses.

What Do the Experts Say?

Recently, colleagues and I conducted an expert elicitation on foodborne illness source attribution as part of an effort to develop a foodborne illness risk ranking model for use in broad federal-level policy evaluation. Over 40 of the country's leading food safety experts participated in the survey. They were able to draw on a broad range of knowledge to inform their judgments—knowledge of microbial ecology, food science, consumption patterns, and food-handling practices as well as epidemiological data. For each of 11 major foodborne pathogens, experts were asked to provide their best judgments of the percentage of cases caused by the pathogen that is associated with consumption of different food categories in a typical year. The food categories spanned the food supply. We then applied these percentages to CDC estimates of the incidence of illness, hospitalization, and death caused by each pathogen to estimate the cases of foodborne illness caused by the pathogen on different foods. These estimates were examined individually and aggregated to provide estimates of foodborne illness by food categories.

The purpose of the study was three fold. First, we needed a consistent set of estimates—spanning all foods—of the association of foodborne illness with food consumption. Second, we aimed to capture information on sporadic illnesses as well as outbreaks. And third, we intended to assess the extent of agreement among experts and the degree of confidence that food safety experts have in their own understanding of the association between foodborne illness and the consumption of specific foods.

The most marked finding is the relatively high public health impact of a small number of pathogens and foods (see Table 1). Prior research indicates that the three highest-ranked pathogens account for 97 percent of all foodborne illnesses. Our results suggest that incidence is also highly concentrated by food. Four food groups (produce, seafood, poultry, and ready-to-eat meat) accounted for 60 percent of all illnesses, 59 percent of all hospitalizations, and 46 percent of all deaths.

The results also show the importance of focusing public and private intervention efforts on particular food-pathogen combinations. A small number of such pairs account for most of the public health burden from foodborne pathogens. Fifteen out of 121 food-pathogen pairs accounted for 90 percent of all illnesses, 25 pairs accounted for 90 percent of hospitalizations, and 21 pairs accounted for 90 percent of deaths. It is worth noting that these foods and pathogens do not rank highly if they were ranked by themselves.

Our study characterized the uncertainty around attribution by pathogens, foods, and food-pathogen pairs by evaluating the level of agreement among experts, the 90 percent confidence bounds they provided, and how their judgments matched up to outbreak data (see Table 2). This information on uncertainty about attribution provides part of the foundation for deciding where to invest in further research and data collection on disease surveillance.

For some food-pathogen pairs, such as *Vibrio* on seafood, experts' best judgments are highly correlated with each other and with the outbreak-based attribution estimate, and their mean confidence "intervals" (the distance between the 5 percent upper and lower confidence bounds) are narrow with little variation among experts. For others, such as *Campylobacter* on produce, the mean and variance of experts' confidence intervals are small, but the correlation between expert judgment and outbreak-based attribution estimate is low. This is a case where experts agree that outbreak data do not provide a good attribution estimate but do agree based on other information, such as strong microbial ecology data. And then there are cases, such as *Toxoplasma* on many foods, where expert's best estimates are not highly correlated with each other or the outbreak-based estimate, and the mean and variance of their confidence intervals are relatively high. This scenario indicates a clear lack of evidence and strongly suggests that more research is needed to understand *Toxoplasmosis* attribution to food.

Table 1.
Expert Judgment-based Estimates of the Incidence of Foodborne Illness and Death by Foods

Food Category	Percent of total cases*	Percent of total deaths**
Produce	29.4	11.9
Seafood	24.8	7.1
Poultry	15.8	16.9
Luncheon and other meats	7.1	17.2
Breads and bakery	4.2	0.6
Dairy	4.1	10.3
Eggs	3.5	7.2
Beverages	3.4	1.1
Beef	3.4	11.3
Pork	3.1	11.4
Game	1.1	5.2
Total	100	100

* Total cases: 12,908,605
** Total deaths: 1,765

Source: Hoffmann et al. 2007a.

Rationalizing Federal Food Safety Policy

U.S. agencies are proposing to or currently make use of food attribution estimates in a number of ways including risk-based inspections, health-based performance standards, and the rationalization of federal food safety policy. In an effort to prioritize the use of limited inspection resources, the Food and Drug Administration's Food Protection Plan includes risk-based targeting of inspection of both domestic plants and imports. The Department of Agriculture's Food Safety Inspection Service has also proposed risk-based inspections of domestic meat-processing and slaughter facilities. Both efforts have proven controversial: consumer groups have expressed concern that a move from random or uniform allocation of inspection resources to risk-based allocation may not ensure product safety and that existing data are not adequate to support the shift. Improved source attribution estimates could play a role here.

Every industrialized country should have good information on how foodborne illnesses are distributed across the food supply, at least in theory. But data on these relationships are more difficult to collect than one might imagine. Changes in international trade law have also made the collection of such data more crucial than it may have been in the past. Governments around the world, including that of the United States, have made a focused effort over the past 10 to 15 years to improve the quality of information on the distribution of foodborne illness across foods. Eventually, this information will help both government agencies and private firms do a more effective, more efficient job of protecting the public from foodborne illness. But for now, a great deal of work remains to be done. ■

A longer version of this article appears in the summer 2009 issue of *Choices*, a publication of the Agricultural & Applied Economics Association.

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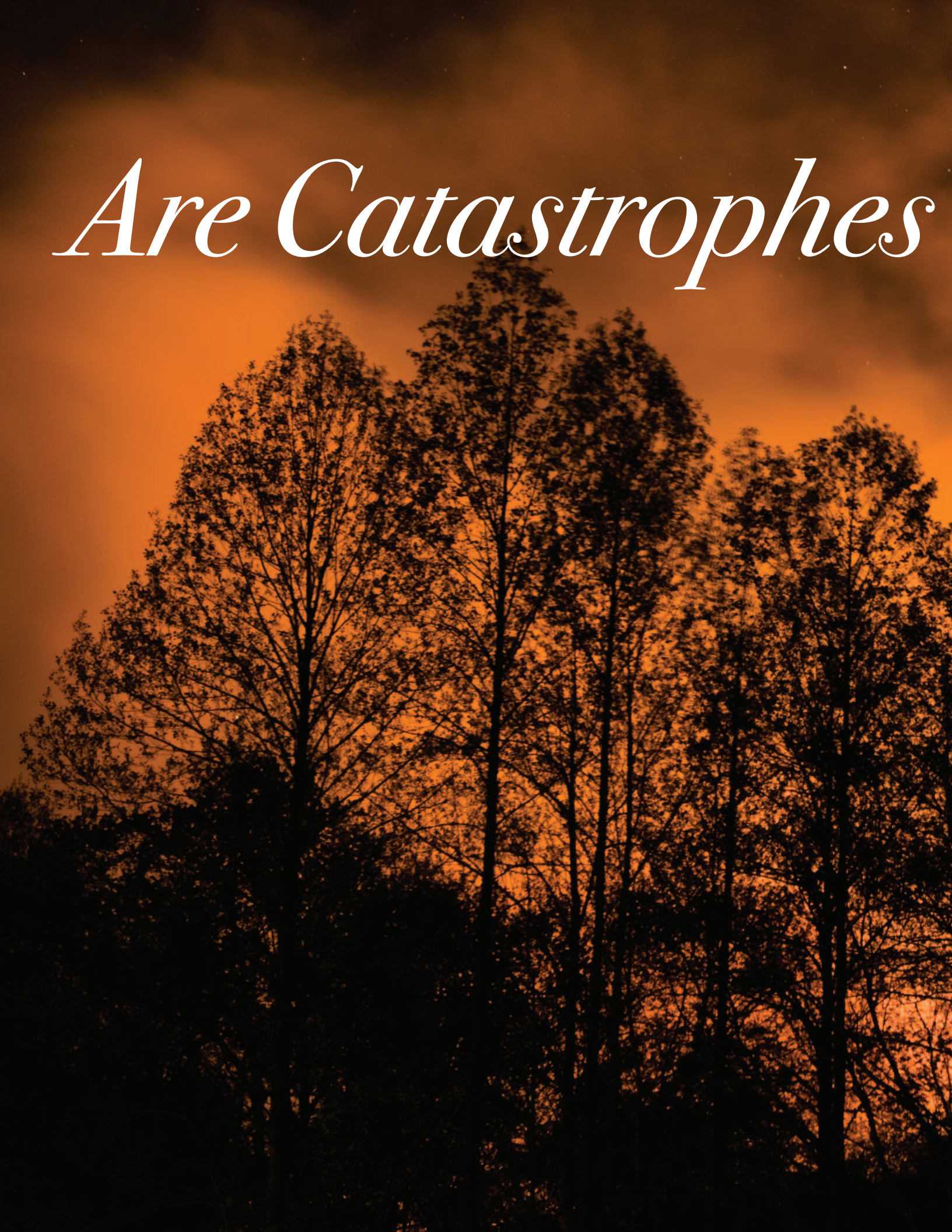
Table 2. Implications of Uncertainty Measures for Regulatory Decisionmakers

	UNCERTAINTY MEASURE					
Case	Agreement among experts	Individual uncertainty	Agreement with an existing estimate	Variability in individual uncertainty	Characterization of uncertainty	Implication for decisions
1	high	low	high	low	Confident agreement about the existing estimate.	Act on the prior.
2	high	low	low	low	Confident agreement about an alternative estimate.	Identify and likely act on alternative estimate.
3	low	low	low	low	Confident disagreement, possibly due to multiple disciplinary views.	Determine and evaluate the source of disagreement before acting.
4	high	high	low	low	Agreement on, but uncertainty about, an alternative estimate.	May warrant further primary research.
5	high	high	high	low	Agreement on, but uncertainty about, the existing estimate.	May warrant further primary research.
6	low	high	low	low	Disagreement and substantial uncertainty about any estimate.	A strong indication of a need for further research.
7	low	high	low	high	Disagreement and variability in individual uncertainty, some are quite certain and others not.	May give insight into where to start further research.
8	low	high	high	low	Illogical.	
9	low	low	high	low	Illogical.	

Source: Hoffmann et al. 2007b.

Are Catastrophes



Insurable?

ROGER M. COOKE AND CAROLYN KOUSKY

The economic costs of natural disasters in the United States (adjusted for inflation) have been increasing in recent decades. The primary reason for this is more people living and working in hazardous areas—and where there are people, there is infrastructure, capital investment, and economic activity. Moreover, some speculate that as the climate changes, the magnitude and/or frequency of certain extreme events may increase, amplifying this trend. This raises important questions about our current and future ability to manage and insure catastrophic risks, such as hurricanes and flooding.

In new research, we have been examining the distributions of damages from natural disasters. These distributions are a joint product of nature (the severity of the hazard) and society (where and how we build).

Three aspects of historical damage distributions—often neglected in policy discussions—are confounding our ability to effectively manage and insure catastrophe risks. The first is **fat tails**, the fact that the probability of an extreme event declines slowly, relative to how bad it is. With fat tails, damages from a 1-in-20-year event are not simply worse than those from a 1-in-10-year event; they are much worse. Second is **tail dependence**, the propensity of severe losses to happen together. For instance, a strong earthquake can cause fires to break out, leading to losses from two events instead of one. And the third is **microcorrelations**, negligible correlations that may be individually harmless, but very dangerous in concert. Weather patterns can induce tiny correlations in weather events in disparate parts of the globe. If an insurance company buys many similar policies in each area, thinking it has diversified, the aggregation of these microcorrelations could come back to hurt it. Traditional statistical techniques do not do an adequate job of detecting, measuring, or analyzing these three phenomena. Our research aims to improve this.

Many distributions we encounter in everyday life—running speeds, IQ scores, height—are "thin tailed." This means that we do not observe really extreme values. Suppose the tallest person we have ever seen is 6 feet, 7 inches. The average person taller than that will not be that much taller: he might be 6 feet, 10 inches, but he will not be 14 feet. Damage distributions from many disasters, on the other hand, are "fat tailed," and there is a greater possibility of witnessing very extreme values. Consider hurricanes: the National Hurricane Center estimates that Katrina caused over $84 billion in damages, considerably more than the second-costliest hurricane, Andrew, in 1992, which caused $40 billion in damages (estimates in 2006$). With fat tails, the next hurricane that is at least as costly as Katrina is expected, on average, to cause much more damage.

One of the challenges associated with fat-tailed risks is that data from a short period of time is not enough to adequately evaluate the potential for and amount of damages. In 1981, the National Flood Insurance Program (NFIP) adopted the goal of becoming financially self-supporting for the "historical average loss year." Floods can be catastrophic, however, and without a catastrophe in the historical experience of the program, the NFIP was unprepared for Hurricane Katrina. Figure 1 shows premiums minus losses by year for the program. The dramatic losses in 2005 are apparent.

Current NFIP rates count only 1 percent of the 2005 losses in calculating the supposed "historical average." The claims in 2005 sent the program deeply into debt, and with a mere 1 percent weighting to 2005, the NFIP, by its own admission, will be unable to pay even the interest on its debt to the Treasury. The program is thus not financially self-supporting.

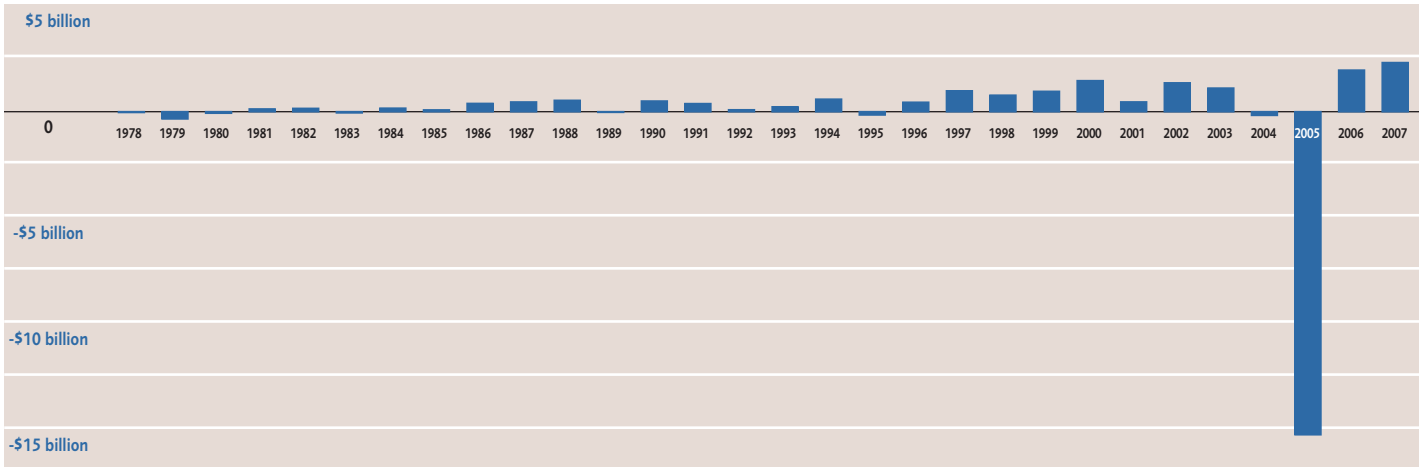
Tails can be so fat that the variance is infinite. When insurance policies are aggregated from a distribution that has a finite variance, the tails are thin. This is good news for insurance companies. The bad news is that if the variance is infinite—meaning as the sample size increases, the sample variance keeps growing—the tails stay fat. The tail behavior of natural disaster damage data we have studied points to infinite variance.

Distributions with infinite variance also defy normal methods for analyzing risk. For such distributions, the average loss will not converge as we consider more data; instead, it will whiplash back and forth. For the NFIP, the average annual amount of claims before 2004 was $553 million. When 2004 and 2005 are included, the figure jumps to $1.18 billion (claims are in constant year 2000$).

When Bad Things Happen Together

Tail dependence refers to the tendency of dependence between two random variables to concentrate in the extreme high values. Simply put, this means bad things happen together. After Hurricane Katrina, Risk Management Solutions, a catastrophe-modeling company, found that lines of insurance that are usually independent all experienced very high claims simultaneously; for example, property, cargo, inland marine and recreational watercraft, floating casinos, onshore energy,

Figure 1. National Flood Insurance Program premiums minus losses per year



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automobile, workers' compensation, health, and life insurance all spiked at once. This demonstrates the ability of extreme events to correlate damages across lines of insurance, locations, and types. Failure to consider this tail dependence could lead an insurance company to underestimate its exposure and thus court insolvency.

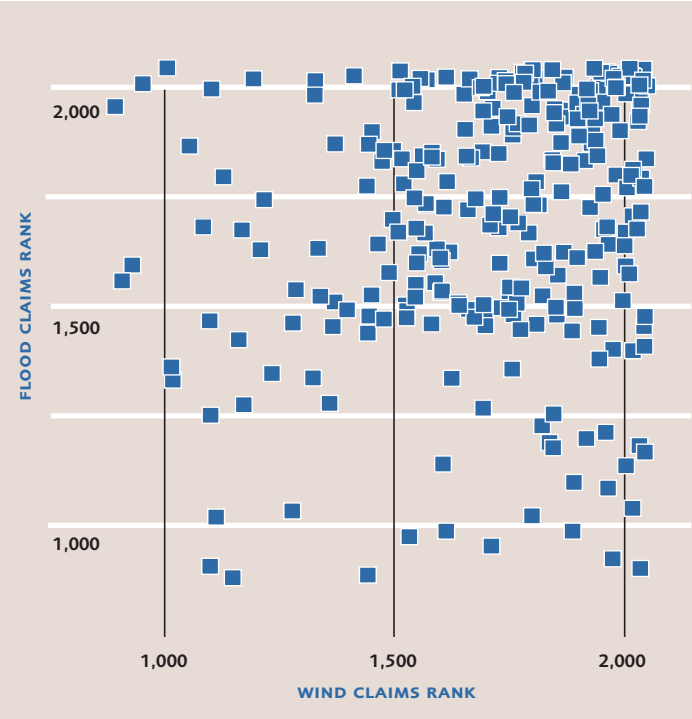
Tail dependence can be seen in loss data. Wind and water damage are insured separately in the United States. The former is covered under homeowners' policies or state wind pools, while the latter is covered by the NFIP. Flood and wind damage are often independent; a rising river does not necessarily mean terrible winds, and a storm with high winds may not have enough rain to cause flooding. A hurricane, however, causes both. This suggests that wind and flood insurance payments may be tail dependent in a hurricane-prone state such as Florida.

Figure 2 shows this is indeed the case. Wind payments from the state insurer Citizens Property Insurance Corporation were grouped by county and month for the years 2002 to 2006, as were NFIP flood claims (all are in constant 2007$). Each damage dataset was ranked by the magnitude of the columns and the ranks plotted against each other. The abundance of points in the upper right quadrant of Figure 2 shows that high flood damage claims and high wind payments occur together, indicative of tail dependence.

Microcorrelations are correlations between variables at or beneath the limit of detection even with lots of data. Suppose we look at the correlation in flood claims between randomly chosen pairs of U.S. counties. Neighboring counties will be correlated if they experience the same flood events, but most correlations are around zero. When we do this for 500 pairs of counties, the average correlation is 0.04 (a correlation of 1 would mean the two counties always flooded simultaneously; a value of -1 would mean whenever one flooded, the other was dry). Indeed, using traditional statistical tools, 91 percent of the correlations would not be statistically distinguishable from zero. But that does not mean they are zero.

Figure 2. **Tail Dependence in Wind and Water Claims, Florida 2002–2006**

Note: Points of zero damages were removed, so axes do not begin at zero.



When the correlations actually are zero, the correlations between aggregations of counties will also fluctuate around zero. This is seen in Figure 3, which plots correlations between individual independent variables (green) and between distinct aggregations of 500 variables (red). Compare this to Figure 4, which shows correlations in county flood claims. The green histogram shows the correlations between individual counties. As just discussed, most are around zero. The blue shows the correlations between groupings of 100 counties, and the red shows the correlations between groupings of 500. With microcorrelations, the correlation between aggregations balloons as seen by comparing the red and green histograms in Figure 4.

Ballooning correlations will put limits on diversification by insurance companies and are particularly alarming since they could so easily go undetected. One might not readily assume that fires in Australia and floods in California are correlated, but El Niño events induce exactly this coupling. Identifying this type of correlation and creating insurance diversification strategies across areas or lines that are truly independent is essential.

Is Federal Intervention Needed?

Insuring risks plagued by fat tails, tail dependence, and microcorrelations is expensive—often much more expensive—than insuring risks without these features. Because there may be many years without severe losses, this fact can be obscured. One or two bad years

can wipe out years of profitability. For the years 1993 to 2003, the Insurance Information Institute calculated that the rate of return on net worth for property insurers in the state of Florida was 25 percent, compared to only 2.8 percent in the rest of the United States. But if you add in the terrible hurricane years of 2004 and 2005, the rate of return on net worth for insurers in Florida drops to -38.1 percent, compared to only -0.7 percent for the rest of the United States.

It has been noted by insurance scholars that state insurance commissioners tend to place more weight on low prices and availability of policies than on solvency considerations or management of catastrophe risk. Homeowners' unhappiness with high premiums has led state regulators to suppress rates (keeping rates lower than they would be otherwise) and compress rates (decreasing the variation in rates across geographic locations) rather than allow rates that would be truly risk-based.

For risks plagued by our three phenomena, rate suppression and compression could make it unprofitable for insurance companies to operate. If insurers cannot charge prices they feel are sustainable, they may leave the market, as has happened in Florida. This puts greater pressure on residual market mechanisms, namely programs set up by states to provide insurance policies to those people who cannot find a policy in the voluntary market. If rates in these programs are not high enough to cover costs, firms in the voluntary market are usually assessed a fee, and thereby subsidize the residual market. Just recently, Florida increased the rates in its state insurance program because they had previously been too low for the state to be able to pay claims should a major hurricane strike.

Some policymakers and scholars have called for federal intervention in these markets. The federal government can smooth losses over time in a way that is difficult for states or private companies. Several proposals have been advanced in Congress, from the backing of state bonds used to finance claims after a severe event to federal reinsurance for state programs. The difficulty with such proposals is the creation of moral hazard. If the federal government subsidizes state insurance programs, it could encourage the state to provide insurance at rates that are far too low to cover the risk. This encourages nonadaptive behavior such as building in risky areas under inadequate building codes. Taxpayers across the country would unwittingly be underwriting such behavior.

As an alternative to intervening so heavily in the insurance market, the federal government could allow insurance companies to create tax-deferred catastrophe reserves. Insurers could choose to allocate funds to a trust or to a separate account with a firm-specific cap, where funds would accumulate tax-free and be withdrawn only for payment of claims following predefined triggers. The trigger could be based on specific events or firm-specific catastrophic loss levels. Creation of such funds would ensure that more capital is available to cover claims in the event of a catastrophe, thereby potentially increasing the availability and affordability of insurance.

We believe the first step in addressing these risks, however, should be to promote more mitigating activities, which can thin and decouple tails. For example, homes can be built or retrofitted to withstand hurricane winds, rising floodwaters, and earthquakes. Such measures not only benefit the individual homeowner, but also the more mitigation that is done, the more community and economic activities will be able to continue postdisaster. Congress is currently debating legislation that would offer tax credits to homeowners who secure their homes against hurricanes and tornadoes. These measures can have high up-front costs, and the probability of a catastrophe occurring often seems remote to many homeowners. Tax credits could potentially overcome these two barriers and spur more investment in mitigation.

Finally, there are a few cases where we can effectively decouple losses. For instance, the 1906 San Francisco earthquake ruptured gas mains, causing fires, and also ruptured water mains, so the fires could not be put out. Now we can build earthquake-resistant pipes for water and gas lines to ensure that when we have a serious earthquake, we don't also have serious fire damage.

Fat tails, tail dependence, and microcorrelations raise significant challenges for the insurance and management of natural disaster risks. As we better understand the nature of these risks, however, we can design and implement insurance and public policy measures that do not unwittingly leave us exposed to the next catastrophe. ■

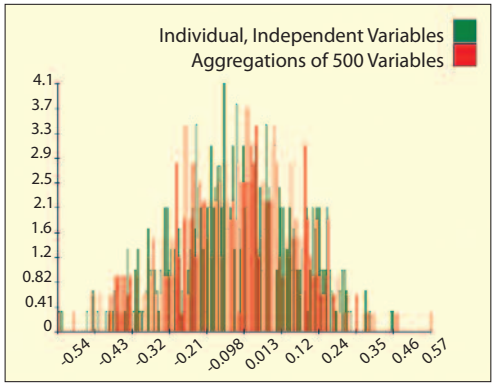


Figure 3. **Independent, Uniform Variables**

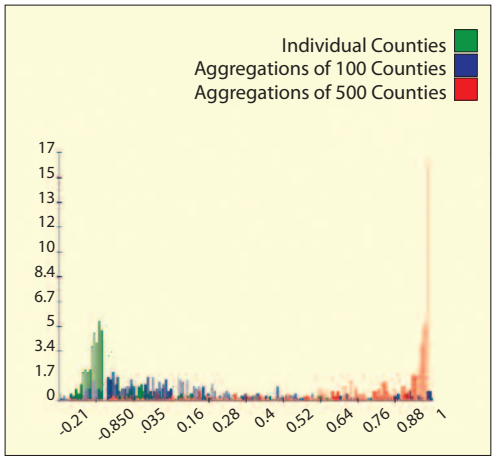


Figure 4. **Flood Claims by County and Year**

RFF Welcomes Four New Members to Board of Directors

PETER R.KAGAN

DEBORAH HECHINGER

RICHARD LEE SCHMALENSEE

Peter R. Kagan *has been with Warburg Pincus since 1997 and co-leads the firm's investment activities in energy and natural resources. He is also a member of the firm's Executive Management Group. Kagan received an BA degree cum laude from Harvard College and JD and MBA degrees with honors from the University of Chicago. Prior to joining Warburg Pincus, he worked in investment banking at Salomon Brothers in both New York and Hong Kong. Kagan is currently on the board of directors of Antero Resources, Broad Oak Energy, Fairfield Energy, Laredo Petroleum, MEG Energy, Targa Resources, and Targa Resources Partners L.P. In addition, he is a member of the Visiting Committee of the University of Chicago Law School.*

1. What environmental issues concern you the most? In my professional life, I regularly concentrate on balancing the need for energy to support economic growth and the importance of environmental sustainability. Issues surrounding the growth and development of alternative energy sources such as wind, solar, and biofuels are areas of focus for me. In addition, I spend considerable time looking at options to minimize the impact of the use of existing resources, including carbon capture and sequestration and the responsible domestic production of cleaner burning natural gas. Finally, as someone who enjoys the outdoors and fishing, I have a personal interest in issues surrounding freshwater preservation.

2. Have you made any "green" changes in your own life? As a New York City resident, I enjoy a carbon-friendly lifestyle. My daily routine involves walking one of my children to school and then walking to work. I spend very little time in a car which helps lower both emissions and stress.

3. What drew you to RFF? Today's resource and environmental problems are complex and challenging. In addition, policy decisions made today can have very long-term consequences. As a result, an organization dedicated to providing nonpartisan, fact-based research on these topics is critical to advancing current policy discussions and focusing attention on issues that are not yet realized or understood.

4. What role do economists have to play in environmental policymaking? Policymaking is about trade-offs. Economic principles and tools are necessary when weighing the consequences and impact of various alternatives. As our country works to minimize its dependence on fossil fuels, policymaking guided by an appreciation for incentives and costs is critical to long-term success.

Deborah Hechinger *recently retired as the president and CEO of BoardSource. She began her career in the Division of Enforcement at the Securities and Exchange Commission. She later served as deputy comptroller as well as director of securities and corporate practices at the Comptroller of the Currency. Before joining BoardSource, she served as executive vice president of World Wildlife Fund. She is currently an independent nonprofit governance and management consultant and also serves on the boards of AllianceBernstein Corporation and the Grand Teton National Park Foundation.*

1. What environmental issues concern you the most? We need to find ways to convert our knowledge about the drivers of climate change into politically and economically feasible policies that address the many challenges we will face in the future. I've long been concerned about the short- and long-term effects of human development on wildlife and wild lands, both here in the United States and abroad. It's important to find ways to value and manage our forests, fisheries, wildlife, water, and other natural resources to ensure their longterm health and sustainability. We all know that our natural resources are valuable because they provide us with health and economic benefits as well as spiritual inspiration, but organizations like RFF help us understand their true economic value, thus facilitating the development of policies that will enhance their protection.

2. Have you made any "green" changes in your own life? I'm sure all of us have become more conscious of the environmental costs of decisions we make in life, big and small. I've changed lots of small things in my personal life—like using energy-efficient lightbulbs and recycling our glass, plastic, and paper waste, as well as reducing paper use and conserving energy. I am lucky enough to live half-time in Wyoming now, which gives me access to Grand Teton National Park where I hike and bike regularly.

3. What drew you to RFF? Policymakers need unbiased, nonpartisan research when designing solutions to the many environmental problems we have today. Just look at the tensions over ways to address climate change, land use, shrinking biodiversity, wildlife use and protection, and deforestation, just to name a few. RFF's research helps policymakers understand how to make better and more effective policy choices regarding the use and conservation of our natural resources.

4. What role do economists have to play in environmental policymaking? It's important that policy solutions address environmental problems in an economically feasible way. Doing so ensures that policies will ameliorate a specific environmental issue, and do so in a way that allocates finite resources on a prioritized basis. This, in turn, permits strategic allocation of societal resources, enhances the chance of community and political acceptance, and preserves capital for future needs. Being able to do more with less lies at the heart of sustainability, whether we're talking about policies or lifestyles.

Trudy Ann Cameron *is the Raymond F. Mikesell Professor of Environmental and Resource Economics at the University of Oregon. She teaches environmental economics at the graduate and undergraduate levels, an undergraduate course in economics for environmental studies and environmental sciences students, as well as graduate econometrics. Cameron specializes in empirical methodologies for environmental benefits estimation, with recent applications to the valuation of reductions in morbidity and mortality risks and climate change prevention and adaptation. She is the most recent past president of the Association of Environmental and Resource Economists.*

1. What environmental issues concern you the most? Climate change and environmental health have been my main interests. I have been mostly concerned with basic research related to the challenges of measuring environmental benefits for use in cost–benefit analyses.

2. Have you made any "green" changes in your own life? The biggest change? In 2002, I bailed out of Los Angeles, where I spent about 500 hours a year in my car, alone, on LA's freeways. I relocated to Eugene, Oregon, where everyone in my family can walk to work or school.

3. What drew you to RFF? RFF has been the leading environmental research organization since long before I first specialized in the field (which was only in the mid-1980s). I have a very strong interest in doing whatever I can to help the organization maintain and enhance its first-rate research reputation and continue to serve important policy needs.

4. What role do economists have to play in environmental policymaking? Two of the most basic ideas of economics—the notion of opportunity cost and the equimarginal principle—are typically the most relevant insights for those who are charged with making important decisions about the allocation of our society's scarce resources. Almost everyone would agree that a cleaner environment is a good thing, and environmental advocacy is fundamental to the policymaking process. However, we need to keep in mind that society also bears the costs of a cleaner environment—in the form of higher prices, lower wages, and lower investment returns. Economists can help policymakers in their efforts to obtain the greatest possible good for society, for any given cost, by focusing attention on the types of trade-offs that need to be made and the distributional consequences that need to be considered.

Richard Lee "Dick" Schmalensee *is the Howard W. Johnson Professor of Economics and Management at MIT and director of the MIT Center for Energy and Environmental Policy Research. He served as the John C. Head III Dean of the MIT Sloan School of Management from 1998 through 2007 and deputy dean from 1996 through 1998. He was a member of the President's Council of Economic Advisors from 1989 through 1991, where he had primary responsibility for energy and environmental policy.*

1. What environmental issues concern you the most? I think climate change is both the most important issue before us and far and away the hardest to deal with because of its international and intergenerational aspects.

2. Have you made any "green" changes in your own life? We moved from a home in the suburbs to a condo on Boston's Back Bay a couple of years ago and drastically reduced both the square footage we occupy and the miles we drive. I would be lying, however, if I said we did this to be green.

3. What drew you to RFF? I have known about and respected RFF and its vital role in energy and environmental economics and policy for decades, and I was absolutely delighted to be invited to join the RFF family.

4. What role do economists have to play in environmental policymaking? Economists, in my experience, are often the only advocates for the broader public interest. Some of the most powerful applications of economics in the policy arena turn on being careful and consistent in the application of basic principles rather than using the fancy theory we learn in graduate school. It is amazing, however, what careless, inconsistent, and just plain silly arguments are sometimes advanced by folks who've never learned that theory! ■

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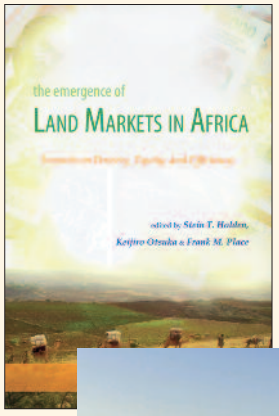

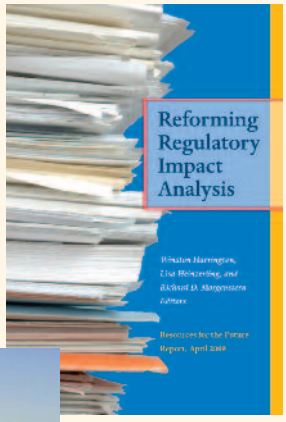

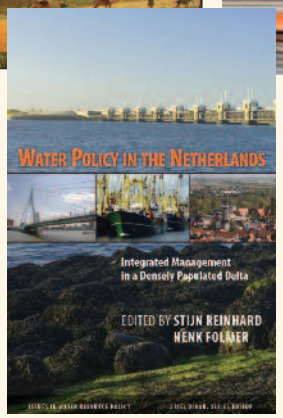

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