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Remote Sensing of Earth from Space: Economic and Policy Issues

Molly K. Macauley and Michael A. Toman

In the United States, the government has been the largest supplier and user of remote-sensing data. The host of uses of these data by the private sector raises several questions: What is the size and urgency of private and public demands for the data? How large and integrated should remote-sensing systems be to meet these demands? How should the data be priced to public and private users? To date, government control of remote sensing has led to inefficient pricing of data outputs and the specter of inefficient future investments in data collection. Private sector involvement could lower the costs of providing remote-sensing data and improve the efficiency of their allocation, while still meeting public sector needs. Appropriate policy measures could include data grants for parties deemed to be acting in the public interest in using remote-sensing data and joint investments in new remote-sensing capacity by public and private providers.

It began by accident in 1963. An astronaut smuggled a simple snapshot camera aboard a Mercury spacecraft and brought back the first civilian photos from space. Tremendous scientific acclaim was accorded to these synoptic views of Earth, leading eventually to a civilian remote-sensing satellite program in the United States.

A host of countries—including the United States, Japan, Canada, Europe, Brazil, India, and the former Soviet Union—has invested nearly $3 billion to date in remote sensing of Earth by civilian satellites. Sensors on the satellites use energy waves to detect numerous features of Earth and its atmosphere. The data collected by the sensors are transmitted to stations on the ground and either translated into photographs or, increasingly, into digitized tapes for computerized analysis.

Remote-sensing systems are used to map Earth's topography, identify mineral deposits, delineate land uses, monitor soil and climate conditions, assist in flood control, identify archaeological sites, and monitor utility rights-of-way to help ensure safe operation of gas pipelines. In addition, these systems are a powerful tool for learning more about the complex processes governing Earth's oceans and atmosphere, thus improving man's ability to understand and respond to potential climate change and other human impacts on natural systems.

Because remote-sensing data provide information about both public goods, such as environmental quality, and private goods, such as oil deposits, substantial controversy has always surrounded public policy about who should pay for remote sensing. This controversy was evident in congressional debate during 1991 about shortcomings of the Land Remote Sensing Commercialization Act (LRSCA), which had been passed by Congress in 1984. LRSCA sought to transfer operation of Landsat, the civilian remote-sensing system owned, operated, and funded by the government, to a private contractor. Under the act the government would retain ownership of Landsat and, for a few years, would subsidize the private firm taking over its operation. Congress also faced a controversial proposal to spend $53 billion on the Earth Observing System (EOS), a set of large satellites that would monitor climate change.

The policy challenges

Remote-sensing data, like other types of information, are an unusual commodity. Information has value only when it influences a decision. In the case of Earth observations from space, one public policy challenge arises from the difficulty of determining how much and what kind of remote-sensing information would be most valuable when information-collecting sensors and the spacecraft that carry them are still in the design stage. The fact that remote sensing provides information about both private goods and public goods complicates this determination. Establishing the value of information about public goods is problematic because the valuation of these goods is itself uncertain.

Another policy challenge concerns determination of the appropriate level and composition of investment in the supply of remote-sensing information. Particularly challenging is the question of what would be the most cost-effective scale of system in which to invest. The traditional notion that space technologies, including remote sensing, must be large-scale and serve multiple purposes is being increasingly questioned. Smaller satellites, each specializing in the collection of different types of data; photographs taken from aircraft rather than from satellites; and conventional ground-based data collection may provide close substitutes for large space-based systems. Analogous technological substitution is found in the electric utility industry, where large-scale systems for electricity generation are giving way to cheaper and more flexible smaller systems.

Yet another policy challenge concerns how remote-sensing information should be priced. Once there is an investment in infrastructure to obtain remote-sensing data, copies of the data typically can be made at little expense. Since it costs so little to satisfy the demand of additional users for the data once the data have been collected, the total benefit to users is greatest if the information is sold at prices near zero. But at such prices the market would not cover infrastructure costs, provide incentives for technological innovation, and protect intellectual property. The problem also arises in the manufacture and distribution of software, in publishing, in the supply of video movie rentals, in the provision of stock market quotations, and in public utility services. In these activities, the pricing problem is addressed principally by the use of customer-differentiated prices, though debate continues about the efficacy of such pricing policies.

Small satellites, each collecting different types of data; photographs taken from aircraft; and ground-based data collection may provide close substitutes for large space-based remote-sensing systems.

In light of the above challenges, it is not surprising that public policy has been difficult to formulate for the nation's Earth-observation programs. In particular, the nature of the data makes their provision the exclusive responsibility of neither the public nor private sectors—and each sector would like the other to foot the bill. It is unclear whether the government has to be the data producer, or whether it could be a purchaser of data from private producers to satisfy public needs. In addressing policies related to remote sensing it is necessary to consider, first, the demand side (how much and what kind of information are most worthwhile); second, the supply side (how large and integrated remote-sensing systems should be); and third, pricing issues (how much should be charged to whom).

The demand side

In the United States, broad concerns about issues such as climate change partly motivate a desire to expand remote sensing by preserving Landsat and implementing the planned Earth Observing System. There is no doubt that remote-sensing data could provide some of the information needed to formulate policies concerning public goods such as climate. Given the host of uses of remote-sensing data by the private sector, however, a focus on public goods alone would illuminate neither the relative sizes of private versus public demands for information nor the relative urgency of different demands and the nature of potential substitutes for data collected via space-based remote sensing.

Conventional wisdom holds that the private market for remote-sensing data is quite small. In fact, the size of demand depends on the quality, quantity, and availability of data as well as on ancillary infrastructure like the availability and price of computer hardware, software, and human training. (Even today, space remote-sensing courses are not routinely part of curricula in relevant disciplines such as geology.) As hardware, software, and training become readily available, however, private sector demands for remote-sensing data are likely to increase markedly. This factor is especially important in the planning of remote-sensing systems to be launched far in the future (in the case of the Earth Observing System, nearly a decade from now).

Proposed systems to collect observations of Earth from space

	Large-size spacecraft, each with many instruments[1]	Medium-size spacecraft, each with a few instruments	Medium-size spacecraft, each with a few instruments	Small-size spacecraft, each with a few instruments
Number of spacecraft	6	51	6	57
Number of instruments	90	72	9	57
Cost of total space hardware[2]	18	16	1	4
Cost to instrument ratio[2]	0.20	0.20	0.11	0.07

Sources: Based on J. Hansen, W. Rossow, and I. Fung, "The Missing Data on Global Climate Change," in *Issues in Science and Technology*, Fall 1990, pp. 62–69; Elchison and Associates, "Evolutionary Lightsat Environmental Program," undated; and unpublished data provided by experts on space and remote sensing.

[1] Earth Observing System.

[2] Costs are in billions of 1990 U.S. dollars.

The supply side

Small scale, redundancy and modularity of capacity, diversity of production methods, and capability for quick turnaround are attributes of a growing number of industries, including computers, telecommunications, and publishing. They are also becoming attributes of traditionally large-scale industries like steel and auto production and electricity generation. In addition, growth in employment and sales revenue is increasingly the province of small- and medium-size businesses and new entrepreneurial companies, especially in high technology, software, and information services industries.

The above attributes and resulting trends in growth of employment and sales revenue have not generally been characteristic of space activities and enterprises. Why is this the case? With respect to space-based remote sensing, a partial answer is that the provisions of the Land Remote Sensing Commercialization Act restrict flexibility in setting market-driven prices for data. They also create uncertainty about how government will regulate system capabilities such as licensing, data access (for national security or the conduct of basic science research, for example), and operating parameters like spatial resolution (how much detail the spacecraft's sensors are permitted to "see"). In many business plans for new private sector ventures in Earth observation, legal costs budgeted to comply with or challenge LRSCA regulations alone add some 40 to 80 percent to the expected costs of establishing the venture.

These regulatory impediments and costs could be accepted without too much thought if there was a clear-cut case for government monopoly in the provision of Earth-observation information. But such a case has not been made, and there is in fact growing evidence that points to the disadvantages of government monopoly. For instance, larger-scale, more comprehensive remote-sensing systems may well be disproportionately costly to operate relative to smaller-scale, less comprehensive systems that could be operated privately for commercial purposes or under contract to the government to satisfy governmental data needs.

A comparison of the cost (in 1990 dollars) of the total space hardware (including launch) for the proposed Earth Observing System with that for each of three smaller-scale remote-sensing systems that have been proposed offers some evidence about this cost difference (see table, p. 3). For EOS, which involves a few large-size spacecraft, each with many instruments, this cost is estimated to be $18 billion. For a system involving many medium-size spacecraft, each with a few instruments, the cost drops to $16 billion. For a system involving a few medium-size spacecraft, each with a few instruments, and a system involving many small-size spacecraft, each with one or two instruments, the costs are $1 billion and $4 billion, respectively. The ratio of the total space hardware cost to the number of instruments carried by the system is 0.20 for EOS and the system with many medium-size spacecraft. This ratio drops to 0.11 for the system with a few medium-size spacecraft and to 0.07 for the system with many small-size spacecraft. (The number of instruments is a rough proxy for the richness of information produced by each system.)

Based on these rough cost estimates, smaller-scale systems indeed look attractive, although there is some concern that the quality of data obtained from these systems could be lower. This concern arises from the possibility that data obtained from separate systems might not be coordinated as well as data obtained from one large integrated system. However, there are ways in which this coordination problem can be overcome in post-collection data processing.

The only area where there is a fairly clear-cut argument for central control of remote sensing is the operation of fixed facilities for launching and tracking spacecraft. But even here concerns have arisen about whether government control of access to space creates an unnecessary barrier for new, creative applications of space technology.

Pricing policies

The difficulty of setting a price for an information commodity like remote sensing has also been at the heart of debate about Earth observations from space. Proposed congressional legislation (H.R. 3614) would amend LRSCA to establish two tiers of pricing, one tier for educational and other nonprofit users set at marginal cost, and one tier for for-profit users set at a higher level to provide opportunities for recovering infrastructure costs. It is not clear how the groups would be distinguished or how marginal cost would be defined under this policy, but if past experience with the pricing of services of the nation's space shuttle is any guide, charges to favored users might be set equal to "additive cost"—the direct out-of-pocket expenses for extending data availability to another user, without any provision for recovering capital depreciation and replacement charges. A price equal to additive cost likely would be very low.

Marginal-cost pricing, particularly when based on additive costs, is likely to have several undesirable side effects. Presumably the capital costs would be recovered from other users, especially commercial users. However, it is not clear that this approach would provide fiscal solvency for either a private or a public remote-sensing program. If the price of remote-sensing data is set too high, commercial users could turn to foreign vendors of space-based information or to alternative modes of information acquisition, such as data gathering on the ground or by airplane. Thus, while marginal-cost pricing would not thwart access to data for important public purposes (science and education), it could have the ironic side effect of perpetuating one of the very problems driving current policy change: the inability to make remote sensing financially sustainable, whether or not it is privatized.

Loading capital costs on nonfavored customers also creates difficulties in enforcing limitations on the acquisition of remote-sensing data by favored users—difficulties acknowledged by H.R. 3614. For-profit firms in the Landsat industry typically use academic or other nonprofit organizations as consultants, as do most for-profit firms in the environmental and resource management industries. A natural result of the proposed two-tier pricing system, then, would be "free" data acquisition by for-profit firms via nonprofit associates. If prices to for-profit users were set high enough to cover Landsat's capital costs, the attractiveness of data acquisition through a nonprofit associate would be especially strong and, like the effect of marginal-cost pricing, would threaten the financial sustainability of the system.

These disadvantages of marginal-cost pricing for favored customers are even more serious for potential entrants into the Landsat industry. They might be less of a problem if the best design of a remote-sensing system was self-evident. However, with uncertainty about the best design, barriers to entry may prove insurmountable. Data prices set at additive cost also offer little clue as to the value of different types of information, thus clouding investment decisions for entrepreneurs if the remote-sensing technologies are supplied by the private sector, and for taxpayers if these technologies remain in the public sector.

The pricing of remote-sensing data at short-run marginal cost could make remote sensing from space financially unsustainable and could limit the potential of private operators to profit from the provision of these data.

How might effective pricing rules for Earth-observation data be constructed? The discussion above suggests that while marginal-cost pricing may maximize users' benefits, it is unlikely to be financially viable in practice. Moreover, in an environment of great uncertainty about the value of information and the technical possibilities for supplying it, such pricing limits the possibility for profitable entry by new, innovative operators and obscures the priorities that users have for different types of information. To avoid undue entry limits and provide for cost recovery, prices should be set so that on average they recover the long-run cost, including capital replacement charges, of the data provision service. Where prices are set above marginal cost to recover fixed expenses, users making the least flexible demands should pay relatively more in order to minimize distortions on the demand side. Contrary to conventional wisdom, it may be that on this basis groups providing public benefits would shoulder a greater share of the burden than commercial users if the latter have more competitive options for obtaining data.

Such an approach obviously raises the question of whether public interests can be adequately served in the absence of preferential pricing. One strategy that could meet social goals in the acquisition of information and retain the possibility for efficient pricing is the use of information vouchers. These vouchers would take the form of data access grants. The grants would be given to scientists, nonprofit organizations, and others deemed to be acting in the public interest in using remote-sensing data. Because the grants would subsidize the purchase of data, they would not require distortions in the price of data to accommodate the public interest. It would be much easier to monitor these grants than it would be to ensure that below-cost data sales are restricted to preferred groups.

Data grants might also be used to accommodate foreign policy goals, including respect for an "open skies" policy. This policy, implied by a 1963 resolution of the United Nations General Assembly, has been interpreted to mean that access to civil remote-sensing data should be permitted for all countries. "Access" has frequently been interpreted to mean either the provision of data without fee or at the same (low) price to all countries, even if their demands differ. To reconcile the goals of accessibility of data and financial solvency, special foreign grants for data access could be made available.

Institutional concerns

Because privatization of the provision of remote-sensing data under LRSCA has thus far been ineffective in resolving demand side, supply side, and pricing issues, it might be tempting to conclude that ownership and operation of Earth-observation systems must be largely if not wholly the province of government. As noted, however, this belief is not well substantiated and may indeed be false. Participation by the private sector in the provision of remote-sensing data offers several possible advantages and may well be feasible if economically sound government policies are pursued.

At least two strategies might offer significant opportunities for private sector involvement without risk to the financial viability of space-based remote sensing. One strategy is to remove barriers to the use of small-scale remote-sensing systems. If the viability of such small-scale systems is in doubt because ventures involving these systems are considered too risky, capital costs still too large, or markets still too small, an alternative strategy would be to allow consortia of public and private information providers to jointly undertake investments in new remote-sensing capacity. These providers would still remain competitors in the downstream provision of different information services to users. Such competitive joint ventures (CJVs) have been sanctioned by the U.S. Department of Justice in cases involving other industries.

The design of a CJV would be based on the number and diversity of products to be provided by a consortium. A neutral party (perhaps a contractor hired by the consortium) would operate the venture to avoid favoritism. No party would be barred from the consortium as long as it paid a share of the fixed costs of general facilities and overhead as well as the incremental cost that the consortium would bear in providing an additional product (for example, the cost of adding and operating another sensor). Nor would joining a consortium be obligatory. (A potential supplier would not want to become a member if it thought it could supply a product at lower cost on its own.) Pricing of services by consortium members would be unregulated, assuming there would be sufficient competition in downstream marketing.

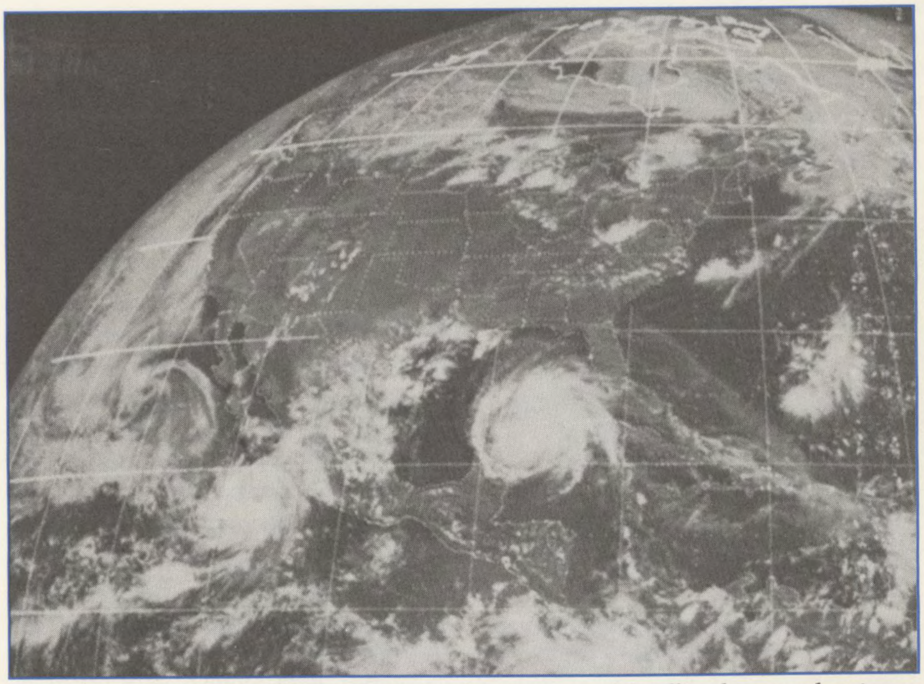

Photo courtesy of the National Oceanic and Atmospheric Administration

This image from the Geostationary Operational Environmental Satellite shows two hurricanes bearing down on the North American continent. Monitoring of weather conditions is one of the public sectors uses of remote-sensing data.

The competitive joint venture seems to offer several potential advantages. It provides natural incentives for consortium members to exploit as many system design economies as are available without overbuilding the data-collection system. Competition among members can promote efficient pricing of information services. Public information needs can be met through data grants to consortium members. And any party that can cost-effectively meet a market demand is able to enter the industry.

In pursuing a competitive joint venture for the provision of remote-sensing data, one important practical challenge is ensuring that entry is not unduly restricted. Consortium members could misrepresent the costs of expanding the size or scope of the their data-collection system to deter new entrants from seeking membership. They could also limit entrants' access to overhead facilities like those for the launch and guidance of spacecraft by charging them an excessive share of the cost of maintaining and operating these facilities. Given its multiple roles as provider of data, user of data, and arbiter of disputes such as who has access to data, the government may find it difficult to oversee entry into CJVs.

Fostering fundamental changes in institutions and policies is never simple, especially when large organizations with entrenched interests are involved. But in light of the many challenges facing U.S. remote sensing—serving growing public and commercial needs and fostering innovation while remaining cost-effective—it seems likely that such changes are inevitable.

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Scenarios of Future U.S. Agricultural Production and Technology and Their Environmental Costs

Pierre R. Crosson

What will be the environmental consequences of U.S. agricultural production between 1991 and 2010? Since the increase in this production will be largely driven by export demand, the contribution of the United States to world trade in grains and soybeans (the country's two largest export crops) should offer a clue to these consequences. U.S. production of these crops will be higher than in 1991 even if the United States loses some of its present shares in this trade. Damage to the environment will not be proportional to increases in production, due to changes in agricultural technologies and environmental policies that will alter the physical connection between this damage and production. Moreover, increases in demand for environmental resources will tend to increase the social costs per unit of physical damage.

There is mounting concern about the long-term impacts of U.S. agriculture on the nation's environment. The concern centers mainly on the reduction of soil productivity and water quality because of soil erosion, the pollution of ground and surface waters by pesticides and fertilizers, and the loss of wildlife habitat through the clearing of woodlands and the draining of wetlands for crop production.

It is useful to think of these environmental consequences of agriculture as the outcome of five sequentially linked factors: (1) the quantity of production; (2) the technologies and management practices used in production; (3) the effects of these technologies and practices on the physical productivity of land and water (such as the number of kilos of corn produced per hectare per year), on the quantity and quality of plant and animal habitat, on concentrations of wastes (such as sediment and agricultural chemicals) in water runoff from land and in groundwater; (4) the effects of these wastes on the quantity and quality of the receiving media—land, water, and the atmosphere—and on human health; and (5) the effects of the third and fourth factors on the social value of land, water, and atmospheric resources.

The consequences of the third and fourth factors are measured in physical units, such as a hectare of lost habitat on a unit increase in a measure of water turbidity. The consequences of the fifth factor are measured in dollars—that is, the dollar value of the physical damages resulting from the third and fourth factors.

For environmental policy, it is the social value of the damages that counts. There is an implicit philosophical assumption here—not shared by all—that policy legitimately deals only with damages to resources that humans value. Thus an increase in the turbidity of water that has no direct or indirect value to humans, either in the present or in the future, is not a reason for policy action to clean up the water.

Many losses of social value are not reflected in market transactions. Economists have developed survey and other techniques to estimate social values, but comprehensive estimates—for example, of the social value of annual losses of wildlife habitat when farmers drain wetlands—are not available. In recognition of this, much environmental policy uses physical measures to set standards of maximum acceptable environmental damage. For example, a concentration of nitrate-nitrogen in groundwater in excess of 10 parts per million is considered a threat to humans consuming the water and particularly to babies in whom ingestion may cause methemoglobinemia ("blue baby syndrome").

The focus in this article is primarily on physical measures of environmental damage due to agricultural production. In this connection it is important to note that the social value of damage can change even if the physical measures of damage do not. Because of rising population and income in the United States, demand for the nation's environmental resources increases over time. Consequently, the social value of a given amount of damage would tend to rise. For example, with the demand for recreational uses of water increasing, the social cost of a given amount of turbidity in water would tend to rise. Constancy in physical measures of environmental damages thus would likely mask increasing losses of social value wherever demand for environmental resources is increasing.

Scenarios of future production and technology

Scenarios are useful for organizing thinking about what the future may hold. They are not predictions, but sketches of certain key features of the future situation based on plausible extensions of existing trends. The following scenarios project the state of U.S. agricultural production and technology and the environmental consequences of this production and technology for the year 2010.

Future U.S. agricultural production will reflect domestic and export demands for food and fiber. Population growth is the main driver of domestic demand. Population projections by the United Nations indicate about a 13 percent increase in the U.S. population between 1990 and 2010. Increases in income can also drive demand for food, but because most Americans now are adequately nourished, these increases will add little to demand.

Exports reflect both the growth of demand in foreign markets and the ability of American farmers to compete in those markets. Foreign demand for food reflects population growth outside the United States and per-capita income growth in the less developed countries (LDCs). According to United Nations projections, 95 percent of global population growth between 1990 and 2010 will be in the LDCs. Because millions of people in these countries are ill-nourished, increases in their incomes would stimulate increases in demand for food.

In the high export demand scenario, U.S. shares in world trade of grains and soybeans are higher than in the baseline scenario due to the increased competitive strength of U.S. farmers.

Studies conducted at Resources for the Future indicate that because of population and income growth in LDCs, these countries will account for 75 percent of the global increase in demand for food between 1990 and 2010. Globally, demand for wheat, feedgrains (corn and sorghum fed to animals), and soybeans, which by weight and use of agricultural resources account for the bulk of U.S. agricultural exports, would increase 26 percent over this period.

To understand how this demand might affect the quantity of U.S. production of wheat, feedgrains, and soybeans, consider three export scenarios. In the first—the baseline scenario—the United States retains its present shares of world trade in the three crops. In the second—the high export demand scenario—the United States increases its shares. In the third—the low export demand scenario—it loses some of its present shares.

In the 1980s the United States accounted for 39 percent of world trade in wheat, 59 percent of the trade in feedgrains (74 percent of the corn trade), and 53 percent of the trade in soybeans. In the baseline scenario these shares remain constant. U.S. exports of the three crops would increase from an annual average of 114 million metric tons (mmt) in 1987/1991 to 161 mmt in 2010. Total production of the crops, for both domestic consumption and export, would rise from 316 mmt in 1987/1991 to 425 mmt in 2010, an increase of 34 percent. The increase in export demand would contribute 50 percent more than the increase in domestic demand to the total production increase.

In the high export demand scenario, production of grains and soybeans is 520 mmt in 2010, about 65 percent higher than in 1987/1991. World trade in these crops grows faster than in the baseline scenario due to more rapid growth in population and per capita income in the less developed countries. U.S. shares of the trade are higher than those projected in the baseline scenario because of the increased competitive strength of the United States in the trade. This strength might result from unexpectedly rapid breakthroughs by American researchers working on agricultural biotechnologies, and from quick adoption of the new technologies by American farmers. The historical record of diffusion of agricultural technology indicates that in time farmers in other countries would adopt the new practices, eroding the increased competitive edge of the United States. In the interim, however, the U.S. advantage could permit American farmers to increase their shares of international markets.

In the low export demand scenario, world trade in grains and soybeans grows

Photo courtesy of the U.S. Department of Agriculture

In conservation tillage, crop residues are left on the ground to reduce the amount of soil carried away by wind and rain. Economics and government policy likely will encourage greater use of this tillage technique.

more slowly than in the baseline scenario. This slower growth reflects slower population and income growth in the LDCs and a successful drive by those countries to increase self-sufficiency in food production. It also reflects the weakened competitive position of the United States due to reduced investment in the development of new agricultural technology and cost-increasing constraints on agriculture to achieve increased environmental protection. The combination of these factors is such that in the low export demand scenario production of grains and soybeans in 2010 is 363 mmt, about 15 percent higher than in 1987/1991.

The differences in production among the three scenarios, when considered along with related differences in technology and management practices, imply

In the low export demand scenario, U.S. shares in world trade of grains and soybeans are lower than in the baseline scenario in part because of the less developed countries' increased self-sufficiency in food production.

quite different consequences for the environment. To determine whether these consequences are likely to be more, less, or about as severe as they are at present, a judgment about the present severity of environmental impacts is needed.

The present situation

The scant evidence available suggests that the expansion of agricultural production over the last forty years has resulted in significant environmental harm. Sediment from agricultural land has caused damage to the quality of the nation's surface waters, although the quality of these waters may have improved due to federal and state policies to reduce industrial and municipal sources of water pollution.

The expansion of production also appears to have caused serious losses of wildlife habitat. Farmers moved away from diversified crop-animal production systems toward more homogeneous crop production systems and removed fences and hedgerows to accommodate larger farm machinery. By reducing vegetative diversity on the farm, these changes had unfavorable impacts on wildlife habitat.

From the mid-1950s to the 1980s, farmers also drained some 12 million to 15 million acres of wetland, primarily in the Mississippi delta and in the northern plains states and Minnesota. Wetlands provide rich habitat for a wide range of wildlife, but especially for migratory waterfowl. Studies show that the number of these birds declined from some 44 million in 1972 to about 28 million in 1985. The loss of wetlands could not be the sole reason for the decline, but it likely was a major contributor.

It is fair to say that when the American people contemplate the environmental consequences of agriculture they think not about damages to the supplies of land and water, to the quality of water, or to natural habitats but about threats to human health from fertilizers and pesticides. The U.S. Environmental Protection Agency's nationwide survey of pesticides and nitrates in wells containing water for human consumption suggests that this may be a misreading of the relative importance of the various kinds of environmental damage. The survey revealed that only about 1 percent of the wells had pesticide concentrations high enough to pose a threat to human health.

It also revealed that about 2 percent of the nation's people (some 4.5 million) drink well water in which nitrate concentrations exceed the U.S. Public Health Service's standard of 10 parts per million. These findings are for numbers of people exposed to contaminated water; they say nothing about how many people may actually have been injured by drinking the water. While the numbers appear small in relation to the total U.S. population, their significance must be carefully assessed. Are damages, or potential damages, to human health to be weighed on the same dollar scale as other environmental damages—for example, an X-million-dollar-per-year loss in recreational

Expansion of U.S. agricultural production over the last forty years has resulted in damage to the nation's water by sediment from farmlands and in losses of wildlife habitat through the draining of wetlands.

uses of water because of sediment damage? Economists, philosophers, and others argue about the question. If, however, the costs of pesticide and nitrate poisonings are valued by the costs of treatment and time lost from work due to illness and death, they likely would not be large in relation to the costs of sediment damage and habitat loss.

Environmental impacts: baseline

If the sequential linkages between agricultural production and the social costs of the resulting environmental damage remain the same as they are at present, then the roughly 34 percent baseline increase in production between 1987/1991 and 2010 would impose a proportional increase in environmental costs. The linkages are not likely to remain the same, however. Changes in agricultural technology and in environmental policies will alter the physical connection between production and damage, and increases in demand for environmental resources will tend to increase the social costs per unit of damage measured in physical units.

The concern of American people about environmental protection almost surely will move the country's agricultural technologies in a less environmentally damaging direction. Research already is under way to find weed and insect control systems less dependent on synthetic inorganic pesticides, although success in making these alternative systems economically attractive to farmers still is in doubt. Should the effort fail, the American people may nonetheless place constraints on pesticide use, accepting the higher costs of food as the price for improvements in the quality of environmental resources.

Trends in fertilizer prices and in technologies of fertilizer use suggest that the amounts of fertilizers used per acre will slowly increase over the next twenty years. The possible effects on human health of the resulting increase of nitrate concentrations in groundwater do not appear seriously threatening, but would bear watching. However, more nitrogen and phosphorus carried by runoff into lakes, reservoirs, and estuaries would stimulate the growth and subsequent decay of aquatic plants, with consequent damage to the quality of these waters. Given continuing increases in the demand for recreational uses of water, the social cost of this damage likely will rise faster than the physical measure of the damage.

For several decades American farmers have been moving toward greater use of tillage techniques that reduce soil erosion by keeping more crop residues on the soil surface. Studies have shown that on sloping land these techniques can reduce erosion by 50 to 90 percent. Both economics and government policy likely will encourage even wider adoption of these techniques, with consequent reductions in soil erosion. However, less soil erosion would not directly translate into less damage from sediments, at least not in the short run. Much previously eroded soil is stored in the many nooks and crannies scattered around the landscape. Consequently, when erosion on farmers' fields is reduced, the water runoff from the fields is free to pick up this stored soil and carry it downstream. Thus deliveries of sediment to places where it causes damage might not be reduced. Even if the deliveries are reduced, the rising demand for recreational uses of water could nonetheless increase the social cost of damage from sediment.

The small increase in cropland in the baseline scenario may imply more habitat loss, particularly if the increase comes from land now in forest or in wetlands. Whether losses in fact are incurred will depend in large part on federal and state policies. The 1985 and 1990 farm bills contained provisions to withhold government program benefits from farmers who violate policies to protect wetlands. And the Bush administration has adopted a policy of no net loss of wetlands. The effectiveness of these various policies has been questioned, but they clearly are aimed in the right direction. As with the case of sediment damages, however, the continuing rise in demand for wetland services could increase the social cost of habitat loss even if the loss in terms of acres were reduced.

Given continuing increases in the demand for recreational uses of water, the social costs of damage to waterways will rise faster than the physical measure of the damage.

In summary, the baseline scenario probably implies some increase in the social costs of environmental damages, particularly those resulting from the decreased quality of surface water and the loss of natural habitats.

Environmental impacts: high and low export demand

In the high export demand scenario, production of grains and soybeans is 95 mmt (22 percent) above the baseline scenario. This scenario clearly would imply greater environmental costs than the baseline scenario unless, because of higher costs, major breakthroughs occurred in pest management, fertilizer use practices, tillage techniques to reduce soil erosion, and measures to improve the productivity of remaining habitat. Absent such breakthroughs, either environmental costs would be greater in the high export demand scenario than in the baseline scenario—probably proportionately more than the difference between production in the two scenarios—or government policies for controlling the environmental costs would push up the economic costs. Either way, the social costs of the high export demand scenario would be sharply higher than those of the baseline scenario.

In the low export demand scenario, production of grains and soybeans is 62 mmt (15 percent) below the baseline scenario. The trends in pest management and in tillage techniques discussed above suggest that the low export demand scenario would imply reduced physical damage to environmental resources by 2010. Although the rising demand for these resources likely would increase the social cost of damage per unit of physical damage, the low export demand scenario by and large does not appear to present a serious threat to the nation's environmental resources.

On balance, the American people are right to be concerned about the implications for the environment of future demands for the nation's agricultural output. The United States is not likely to face a crisis of economic or environmental costs in meeting these demands. But alertness to emerging signs of pressures that would increase these costs, and readiness to move to control these pressures, clearly are called for. Hysteria in misreading the signs of pressure will only make things worse. Coolness in assessment and prudence in action should be our bywords.

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How Certain Is that Environmental Risk Estimate?

Frederick W. Talcott

Sizable uncertainties are associated with each element of quantitative environmental risk assessments. They arise because physical, chemical, and biological phenomena are often difficult to measure and do not function in straightforward, predictable, and linear ways. Although large, ubiquitous, inevitable, and only partly reducible, these uncertainties need not impede decisions about how to deal with environmental problems. Supportable decisions can be made if uncertainties in risk estimates are clearly presented, are reduced where it is cost-effective to do so, are accounted for in comparisons among environmental risks, and are the context for making conservative assumptions.

Most people, and some policymakers, do not recognize the extent of the uncertainties involved in risk assessments that form the basis of many decisions about environmental pollution. Decisions about environmental risks must be made in the face of uncertainties that are far beyond the range of people's commonplace experience. When legislators consider information about risks to health and the environment in setting goals for environmental protection, when agency heads evaluate risks in setting priorities among risk reduction programs, and when state and federal regulators weigh risks in setting limits on emissions or in restricting the use of particular products or substances, their judgments are never made in an atmosphere of certainty. The uncertainties they encounter almost always may be reduced by gathering additional information, but time and cost constraints and some fundamental limits will always leave a sizable amount of uncertainty in any risk estimate.

How sizable is "sizable"? A full assessment of how much or how little is known about the quantities of harmful substances released from different sources, the concentrations of these substances in the environment, and the toxicity of these substances would reveal that actual environmental risks could be higher or lower than estimated risks by factors ranging from tens to hundreds or more. If such uncertainty were characteristic of an individual's income over a one-year period, that income could plausibly range between $5,000 and $500,000, or even between $500 and $5 million.

Evidence shows that the uncertainties in environmental risk estimates (quantitative assessments of health or other risks to humans and other organisms in the environment) are large, ubiquitous, inevitable, and only partly reducible. The magnitude of these uncertainties would be less if physical, chemical, and biological phenomena were easy to understand and to measure and if these phenomena functioned in straightforward, predictable, and linear ways. However, the real world operates in complex ways.

First, important physical or biological relationships are often complicated. For example, the concentration of a substance generally increases in a linear way with the average quantity released. However, the relationship between concentration and quantity becomes less predictable and less linear as situations common in the real world intervene. Shifting or variable winds, physical objects such as buildings, and other factors that affect the dispersion of a substance in the environment can make estimates of concentrations relatively uncertain.

Second, phenomena that are easy to measure, such as average concentrations, can sometimes lead to over- or underestimation of other phenomena that are not so easy to measure, such as instantaneous or peak concentrations. For example, wind-tunnel experiments demonstrate that measurements of the average concentrations of propane within a propane gas cloud can lead to underestimation of the cloud's flammable area because flammability is affected both by average and peak concentrations.

Third, the links between the release of a substance and the consequences of that release are nonlinear, involve several complicating factors, and are probabilistic. For example, records of approximately 500 accidental releases of chlorine gas indicate that the likelihood of human injuries increases with the quantity released, but not proportionately; and the number of persons injured increases, but only roughly in proportion with the quantity released. Moreover, quantity is only one of many factors that determine the ultimate effects of a chemical's release.

Steps in risk estimation

Uncertainty pervades each element of environmental risk assessments, as an examination of estimations of the risks to humans from the release of a harmful substance into the environment illustrates. These estimations all deal (explicitly or implicitly) with the following questions: What is the probability that release of a substance will occur? What quantity of this substance will be released? How will the concentration of this substance change as it disperses from the point of release? How many people or other organisms in the environment will be exposed to this substance? How much of the delivered dose of this substance will be taken up by organisms? And what will be the relationship between a particular dose of this substance and an organism's response—that is, how will the toxic effects of this substance increase with increased dose?

The mathematics in a quantitative risk estimate may become complex, but es-

Range of uncertainty and variability in environmental risk assessments

Geometric standard deviation	Descriptive term	Examples of interpretive phrases
More than 10.00		
	Extremely uncertain Extremely variable	There is a 2 1/2 percent chance that the actual value may be higher than the median by more than a factor of 100 and a 2 1/2 percent chance it will be lower by a factor of .01 or less.
10.00		
	Highly uncertain Highly variable	The value at the upper end of the 95 percent confidence interval is about 625 times larger than the value at the lower end.
5.00		
	Fairly uncertain Fairly variable	The value at the 95th percentile is about 10 times the value of the median and 100 times the value at the 5th percentile.
3.00		
	Moderately uncertain Moderately variable	It is 95 percent sure that the value is not less than one-quarter of the value of the median, and not more than 4 times the value of the median.
2.00		
	Moderately certain Moderately invariable	There is only 1 chance in 40 that the actual value may be greater than twice the median, and the same chance that it may be less than half the median.
1.50		
	Fairly certain Fairly invariable	There is a 5 percent chance that the actual value may be as much as 50 percent higher or lower than the value of the median.
1.25		
	Highly certain Highly invariable	It is 95 percent sure that the actual value is within plus or minus 10 percent of the value of the median.
1.05		
	Extremely certain Extremely invariable	
1.00		There is absolute certainty.

Note: A convenient measure of the best estimate of a value is the median; there is a 50-50 chance that the value is greater than the median, and the same chance that it is less. A convenient measure of the spread of the distribution—that is, the variability or uncertainty of a distribution—is the geometric standard deviation (GSD). The GSD is a number that is greater than or equal to 1. If it is 1, it is certain that the phenomenon being described exactly equals the median. If the GSD is a little more than 1, there is slight uncertainty about the true value of the phenomenon. As the GSD increases, there is increasing uncertainty about the value of the phenomenon.

A lognormal distribution seems to adequately describe the uncertainty in many environmental relationships. When it does, there is a two-thirds chance that the value lies between the median divided by the GSD and the median times the GSD, and there is a 95 percent chance that the value lies between the median divided by the GSD squared and the median times the GSD squared.

sentially each of the elements enters into this estimate in a multiplicative way:

Risk = probability × quantity
× (1/dispersion) × population
× uptake × dose vs. response

An increase in any of these six elements leads to higher estimates of risk levels.

There is always some uncertainty about each of these elements in the risk estimation process. In the discussion below, the terms "extreme certainty" and "extreme uncertainty" denote opposite ends of the spectrum of how well a particular phenomenon is understood, and the modifiers "high," "fair," and "moderate" depict gradations of this understanding (see table, p. 11). These gradations, though arbitrary, are appropriate to the range of uncertainties found in environmental risk analysis.

A gallery of uncertainties

A large body of scientific and engineering studies is available to describe the extent of current uncertainty about each of the elements in the formula above. This information can be summarized as follows.

Probability of a release of a harmful substance. Estimating the probability of a release of a harmful substance may be unnecessary for many environmental risk assessments. It may be known with certainty that a factory is discharging wastes into a waterway or that farmers are using a particular pesticide on a crop. There is no doubt that cars emit pollutants. However, the 1984 release of methyl isocyanate from the Union Carbide plant in Bhopal, India and the more recent spill of oil from the *Exxon Valdez* off the coast of Alaska were accidental. Estimating the probability or frequency of such accidental releases is the first step in many environmental risk assessments.

There is sizable uncertainty about estimates of the probability of accidental releases of harmful substances. Historical data offer some guide to this probability for frequently occurring accidental releases, but are less instructive about some rare kinds of accidents involving certain substances. Examples of such accidents are a large release of radioactive substances from a nuclear power plant or a large release at a chemical plant. Mathematical models developed for estimating the frequency of accidental releases of radioactive substances at nuclear power plants offer a guide to the probability of accidental releases of harmful substances at facilities, such as chemical manufacturing plants, that carry on activities similar in complexity to those conducted at nuclear power plants. Since the models produce fairly uncertain estimates of the probability of accidental releases of radioactive substances, it would appear that most estimates of the probability of chemical releases would be no better than fairly uncertain.

Quantity of a harmful substance released. Estimates of the quantity of harmful substances released into the environment improve with the amount of information gathered. For example, an analyst could estimate the quantity of pollutants emitted into the air by industrial facilities using knowledge of the facilities' production volume and estimates by the Environmental Protection Agency (EPA) of the number of pounds of each pollutant released in the production of one ton of each product. The resulting estimate would be fairly uncertain but could improve to moderately certain if it were based on additional input from the EPA's Toxic Release Inventory, in which 22,000 large manufacturing facilities report estimates of their annual releases of toxic substances.

Dispersion of a harmful substance and resulting concentrations of that substance in the environment. It is possible to obtain results from mathematical simulations of air and water dispersion that correspond well with the results of a particular test release of a substance into air or water. However, in practical situations, estimates of concentrations at particular points in the dispersion pathway range from fairly to highly uncertain.

When risk assessors have actual measurements of concentrations to work with, they can omit estimation of the probability of a release of a substance, the quantity of the substance released, and the dispersion of that substance. However, actual measurements of concentrations of particular substances in the environment reveal that concentrations are highly variable. For instance, measurements show that ambient concentrations of some pollutants are moderately invariable to moderately variable from day to day in a particular season. These concentrations may vary by a factor of 5 to 10 between warm and cold seasons and among different years. Actual measurements show that radon concentrations among the homes in a given locale may be fairly variable. In addition, they show that human exposure to some chemicals in the workplace may be extremely variable among individual work situations.

Population exposed to release of a harmful substance. The pattern of the population of people living in, working in, and visiting an area near the source of a release of a harmful substance influences the degree of risk of adverse effects from that release and, thus, the degree of risk of adverse effects among individuals. In the United States, some industrial sites may have no residential population within 500 yards, or even 3 miles, while others may have population densities ranging from less than 1 to more than 2,000 persons per square mile. In the absence of site-specific data, any estimate of the population potentially exposed to the release of a harmful substance from such sites would be extremely uncertain.

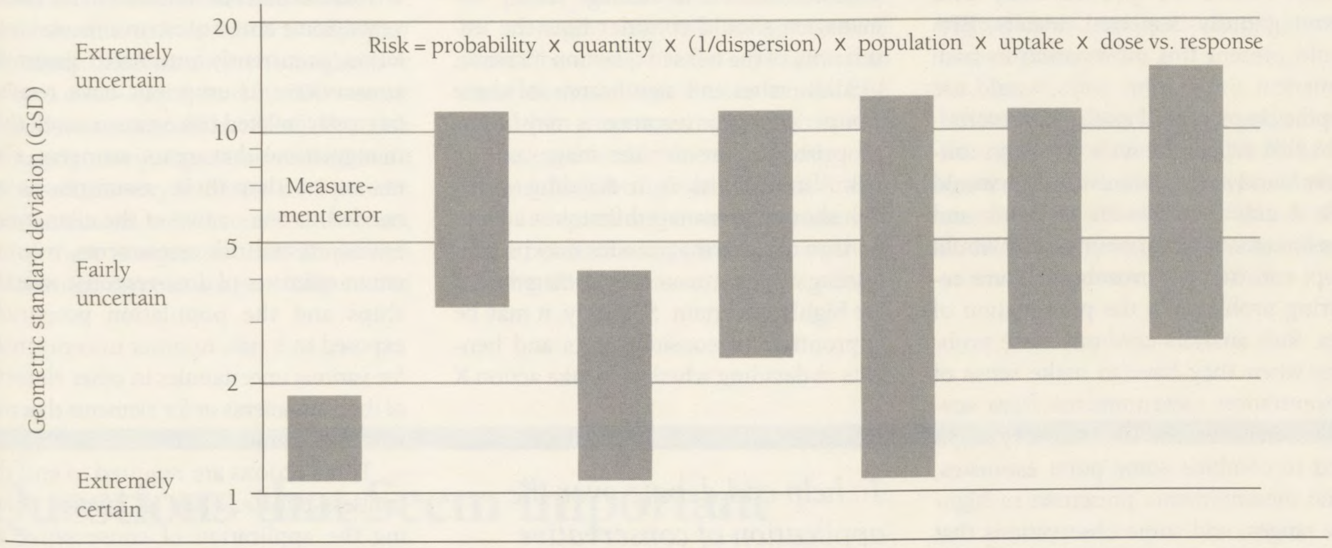
Uptake of harmful substances by humans and other organisms. In the past decade, there has been intense interest in trying to understand the biological mechanisms at work when a human's exposure to a harmful substance leads to harmful concentrations of that substance in each of the individual's internal organs. Scientists have tried to advance such understanding by developing pharmacokinetic models that reflect how the physiology of humans differs from that of test animals with respect to uptake, metabolism, and excretion of particular chemicals. But even the most carefully constructed of these models must rely on estimates of a number of variables, such as how fast a chemical passes from the blood into an organ, that are either difficult or impossible to measure directly in humans and test animals. Pharmacokinetic models may modify risk estimates in significant ways, but their structure and the data they contain make these modifications moderately to extremely uncertain.

Relationship between dose of a harmful substance and adverse toxicological response. A number of variables affect the dose-response relationship—that is, how organisms respond to a particular dose of a harmful substance and how this response changes as the dose increases. The toxicity of a particular dose of a substance not only varies across species, but among individuals of the same species. Sex, age, size, diet, and the route of exposure to a substance, among other variables, affect how toxic increased doses of a substance are to organisms.

Most acute toxicity estimates—for example, estimates of the dose of a substance that would be lethal to half of the subjects in a laboratory test—are moderately uncertain. Estimates of most cancer potency values are even more uncertain. This is because test animals are given higher doses of substances suspected to be carcinogenic than humans would normally receive, and because epidemiologic data linking the incidence of human cancer with such substances is often unavailable or inconclusive. Thus cancer potency estimates are fairly to extremely uncertain.

Measurement error. Measurement error increases the uncertainty associated with each of the above elements in an environmental risk assessment. Given clearly specified protocols and well-calibrated equipment, measurements of physical quantities—such as the concentrations of substances in air, water, food,

Typical ranges of uncertainty in the elements of some environmental risk assessments



Note: Measurement error is an element of any environmental risk assessment. The other elements in the figure are specific to quantitative assessments of health or other risks to humans and other organisms due to the release of a harmful substance into the environment (see formula, p. 11).

and the tissues of organisms—may be highly certain or even extremely certain. But practical constraints, including lack of training and supervision in the use of measurement devices and variability in the precision of these devices, may limit the accuracy of some measurements to the moderately certain range.

Of all the elements of a risk assessment, measurement error generally introduces the least uncertainty. Since the range of uncertainty for dose-response relationships often extends to the extremely uncertain, these relationships are generally the most uncertain element of a risk assessment, followed, in rough order of increasing certainty, by uptake by organisms of a harmful substance, population exposed to the release of a hazardous substance, probability of a release of a hazardous substance, dispersion of a hazardous substance, and quantity of a hazardous substance released (see figure, p. 13). However, this ordering varies with the circumstances in which a particular risk assessment is made. For example, if a wealth of definitive toxicity data are available but other phenomena, such as dispersion patterns, are poorly understood, estimates of dose-response relationships may not be the most uncertain element of the risk assessment.

Overall uncertainty. Uncertainty in each of the elements of a quantitative risk assessment combines to produce an overall uncertainty in the estimate of a particular risk. To date, only a few studies have carefully integrated the uncertainty associated with individual elements of a risk estimation into an overall estimate of a risk and its overall uncertainty. In these studies, estimates of human cancer risks due to exposure to chemicals have been shown to be moderately to extremely uncertain.

Policy implications

Uncertainties in environmental risk assessments are present in all elements of the assessment process, are large, and are inevitable because of practical limitations on the ability to perform enough precise measurements to capture the sizable amount of natural variation and randomness in physical and biological systems. These uncertainties make decisions about environmental problems difficult, but there are several approaches to deal with them.

In order to make supportable, robust, and sound decisions, risk assessors should present the particular level of uncertainty in the risks they are estimating. Risk managers should reduce uncertainty when the reductions would be cost-effective and would affect the choice of risk management option. They should make comparisons among risks and comparisons among actions to manage risks with uncertainties in mind. And, if they must apply conservative assumptions, they should do so in the context of the particular uncertainties of the risk being addressed.

Current environmental risk assessments rarely present estimates of uncertainties in a clear and consistent manner. Competent engineering, toxicological, and other scientific studies routinely indicate the precision of the measurements they use and the confidence with which they estimate relationships, but they present this information in a variety of ways. The Environmental Protection Agency could exercise leadership in this regard by developing standards for the presentation of its own quantitative information so that variability and uncertainty would be prominently and unambiguously displayed. Ideally, EPA would present this information in both numerical and graphic ways, would use graphic displays and statistical distributions that reflect the wide variation routinely found in environmental data, would seek a definitive system of terms and measurements of variability, and would adopt consistent approaches to some recurring problems in the presentation of data. Risk analysts confront these problems when they have to make sense of concentration measurements from several different studies. To do so, they might need to combine some point estimates, some measurements presented in high-low ranges, and some observations that were below the detection limits of measurement devices.

Concerning the reduction of uncertainties encountered in risk estimations, risk managers should be selective. Reducing the uncertainty in any one or more of the elements of a risk assessment will reduce the overall uncertainty of a risk estimate, but not all such reductions are equally cost-effective. In a particular risk assessment, for example, it may be possible to improve estimates of the quantity of a particular substance released from a particular kind of facility from moderately uncertain to fairly certain. However, improving estimates of the population potentially exposed to such a release from extremely uncertain to moderately uncertain would reduce the overall uncertainty more and might also cost much less to accomplish. Risk managers can use the economic concept of the efficient frontier to determine which reductions in uncertainty are likely to reduce overall uncertainty the most and at the lowest cost.

Risk managers should not consider cost-effectiveness to be the only criteria for making an investment in a reduction of uncertainty. Such an investment is worthwhile only if the reduction would be cost-effective and would affect the choice of risk management option.

With respect to making comparisons among environmental risks and among potential actions to manage them, risk managers should consider how the uncertainty of the risks in question increases or diminishes the significance of these comparisons. For instance, it may be appropriate to consider the magnitude of risk A and of risk B in deciding which risk should be managed first, but a comparison of these magnitudes may be misleading when estimates of the magnitudes are highly uncertain. Similarly, it may be appropriate to consider costs and benefits in deciding whether to take action X or action Y to manage a particular risk, but a comparison of the average costs with the average benefits of these actions can be misleading when the uncertainties associated with the risk are large.

To help end debate over the application of conservative assumptions, uncertainties in each element of a risk assessment must be explicitly acknowledged and approximated.

To make more meaningful comparisons and better decisions, risk managers can make use of conceptual tools from the field of decision analysis. For example, Monte Carlo simulations take advantage of the ability of desktop computers to quickly calculate a risk thousands of times. By randomly "drawing" a value for each uncertain variable (using estimates of the uncertainty of each variable to determine how likely each draw should be), these simulations construct a distribution of the overall uncertainty of the risk out of repeated combinations of the random draws from each element in the risk formula.

With regard to making conservative assumptions in the context of uncertainty, risk managers should consider when and how to apply these assumptions. The timing and appropriateness of their application have been a central argument in environmental risk assessment for twenty years. Some critics of environmental regulation, as currently formulated, assert that conservative assumptions have resulted in grossly inflated risk estimates and, thus, in regulations that are too stringent. Others assert that these assumptions are needed in one or two of the elements of environmental risk assessments, most often in estimates of dose-response relationships and the population potentially exposed to a risk, in order to compensate for various uncertainties in other elements of the assessments or for elements that may have been omitted in the assessments.

Three actions are required to end this fruitless debate. They all involve delaying the application of conservative assumptions until the overall risk is estimated and the uncertainty of the risk estimate is assessed, because preemptive safety factors obscure the extent of what is known and what is not about the risk in question. The first action is to explicitly acknowledge and to approximate the uncertainties in each element of the risk estimation process. The second is to carry the uncertainties through the calculation process and to calculate not only the median or mean risk, but its overall uncertainty as well. In its recently released "Guidance on Risk Characterization for Risk Managers and Risk Assessors," EPA appears to endorse these actions in whole or in part.

The third action to end the debate over conservative assumptions is to develop and apply decision criteria that explicitly address acceptable risk levels for individuals and the overall population. If risk managers decide that public policy requires the extra protection that conservative assumptions provide, these assumptions should be reflected in the criteria on which risk management decisions are based and not enmeshed in the risk assessment, where they are hidden from view. Moreover, these criteria must reflect the uncertainties inherent in risk estimations. Risk managers may judge it publicly acceptable for a maximally exposed individual to have a risk of 1 in

10,000 for suffering serious adverse effects from a harmful substance if the risk estimate is at least moderately certain. If, however, the risk estimate is highly or extremely uncertain, the risk might have to be lower—say 1 in 100,000—to be considered acceptable. Similarly, risk managers may judge a risk management policy satisfactory if there is a 75 percent chance that its benefits exceed its costs, but if there is a greater than 25 percent chance that its costs may actually exceed its benefits, they may seek additional information to determine whether a different policy would make a better choice for managing the risk in question. It should be noted that the criteria used in these examples are illustrative. At EPA and other government agencies, criteria for acceptable risk are still evolving.

It is the job of government risk managers to represent the views and interests of the public in setting and applying these criteria. Risk assessors have the obligation and the ability to provide what the risk managers need to do that job—that is, a description of the nature and the magnitude of risks, including the uncertainty of these risks.

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Questions that Seem Important

Robert W. Fri

At a workshop on defining sustainable forestry earlier this year, Resources for the Future (RFF) president Robert W. Fri pondered the implications of a small but diverse collection of research results and commentary plausibly connected with the theme of sustainable development. Citing the work of several RFF researchers, an encyclical by Pope John Paul II, a speech by Russell Train, an article by Mark Sagoff, and a book by Robert Reich, Fri poses three questions. Is sustainable development more likely to thrive under some particular set of political and economic institutions than under others? Should the values that underpin this development become part of mainstream ethical systems? And, if the answer to these questions is yes, are we prepared to live with the results? He concludes that the political, economic, and ethical setting in which sustainable development is pursued will importantly determine whether this development comes about.

One of the joys of being an ordinary mortal at a scholarly place of business like Resources for the Future is trying to make some sense out of the flood of research and analysis that crosses my desk. Part of the material has clear and immediate application to pressing policy issues. The rest adds, I hope, to the intellectual capital on which we can later draw to resolve future issues. Whatever their nature, I value all of these contributions to my education.

In some ways, however, I prize most a small and eclectic stack of research and commentary that I keep in reserve on my desk—a stack I add to only rarely. If it had a label, I suppose this stack would be called "things that seem really important but I don't know why." From time to time, I refer to the papers in it to engage in my own version of desktop publishing—which is to say, I "publish" whatever happens to be on my desk at the time.

The remarks that follow offer an example of my desktop publishing. It may be that what I have to say is plausibly connected with the theme of sustainable forestry that is the focus of this conference and is even important to the broader question of sustainable development itself. I begin by simply outlining the main points of six of the papers I found in my "they must be important" file.

In 1991, Pope John Paul II published an encyclical called *Centesimus Annus*. Papal encyclicals may not be on your usual reading list, but this one should be. In it the pope concludes that politically open, capitalist societies are more likely to promote human dignity and well-being than any other form of social organization. He warns that this is not necessarily the result of open, capitalistic societies and that vigilance is required to make it so. Still, his views are not very different from those Winston Churchill expressed in his famous dictum about democracy—that democracy is far from perfect, but is better than all the other systems—and I can only observe that getting Churchill and the pope on the same side of an issue seems a pretty potent combination. Maybe that's how this encyclical wound up in my pile of things that seem important.

The next document moves us from Paul to Peter, although the Peter in question is Peter M. Morrisette, a fellow at RFF. In a recently released RFF discussion paper, Morrisette poses the question of whether one form of political and economic organization is better than others in protecting the environment—an obvious extension of the ground covered by John Paul. Morrisette's analysis is carefully hedged with scholarly caveats, as it should be for such exploratory work. Interestingly, however, he found that countries with open political systems and capitalist economies tend to have low rates of deforestation. Conversely, nations that lack these characteristics tend to have more rapid deforestation.

My next contributor is the noted conservationist Russell Train, one of nature's aristocrats—a characterization that can be taken any way one likes. In 1990 Russell gave a speech called "Caring for Creation," and he tells me that he got more responses to it than to anything else he ever said. It is a speech about the role of organized religion in environmental matters, a role that so far has been pretty much a walk-on. Russell's thesis is straightforward. He says that "our churches, synagogues, temples, and mosques should be a principal vehicle for instilling environmental values in our planet's people. And believe me, it is very much a matter of values."

Mark Sagoff, a philosopher at the University of Maryland, is also interested in values. His tone is more secular than Train's, but I suppose that goes with the philosophical territory. In an article in the newsletter of the Institute for Philosophy and Public Affairs, Sagoff argues that the traditional preservationist ethic is inadequate to the needs and realities of the twenty-first century. At the same time, he rejects the "gospel of efficiency" on the grounds that it won't work. Even if he thought that it did, I suspect that he would find it too anthropocentric. But that is another matter.

The gospel of efficiency got a couple of RFF scholars into hot water last year, but that should surprise no one. RFF vice president Paul R. Portney and RFF senior fellow Alan J. Krupnick opined in *Science* (April 26, 1991) that the new smog control plan set for Southern California will cost more than it is worth—or, in deference to their careful scholarship, it will cost more than the benefits Portney and Krupnick could quantify. This brave endeavor attracted all of the controversy that you would expect in a subsequent letters to the editor column, giving rise to one of the more entertaining issues of *Science* in recent memory.

My last witness is Robert Reich, whose book *The Work of Nations* should be read by anyone who plans to survive into the twenty-first century. His argument is too complex for easy summarization, so I will only note that he foresees a global economy quite unlike anything we have experienced before. His main point, as I understand it, is that decisions affecting the economic—and, by extension, the environmental—quality of life in any given nation will not be entirely in the hands of that nation. In other words, what's good for General Motors is good for someone, but not necessarily for Americans.

Some provocative questions

It is probably an act of suicidal generalization to make something out of these anecdotal observations, but it may be amusing to watch me try. And it is entirely in that spirit that I will suggest that they may in fact raise some useful questions to ponder.

The first question is this: Is sustainable development more likely to thrive under some particular set of political and economic institutions than under others? The pope seems to think that human dignity is best served by open, capitalistic societies. He is not, so far as I can tell, speaking about the environment, though the parallel is attractive. Peter Morrisette finds tantalizing evidence about social organization and deforestation that at least invites further investigation. And certainly the breakup of the Soviet bloc has revealed that central planning is not especially helpful for environmental quality.

Although this question of the preferred social organization is meant to be a serious one, I should note that it may already have been answered. Open, capitalistic societies are rapidly becoming the world's dominant form of social organization, although not necessarily for environmental reasons. In its year-end issue, *Newsweek* (December 30, 1991) reported that, "over the last three years, roughly one-third of the countries on the planet have decided to transform their political systems into more democratic ones. For the first time, democracies represented an absolute majority of the world's nations." And I suspect that Reich is also right in believing that global economic institutions are changing both quickly and profoundly toward decentralization. Given these trends, there is something to be said for those of us who are concerned with environmental issues to pay close attention to their consequences.

The second question is not unrelated: Should the values that underpin sustainable development become part of mainstream ethical systems? Note that this question does not ask whether we need better or more widely accepted environmental values. I suspect that we do and that Sagoff is right in maintaining that neither the preservationist nor conservationist values of this century should persist unexamined into the next century. But one could imagine a set of new and improved values attached to sustainable development that are independent of the world's major ethical systems, religious or secular. The more important question, and the one I pose here, is whether environmental values should become a part of these mainstream systems.

This question is the one that Russell Train addresses, and his answer is clearly yes. Further, I would submit that the concept of sustainable development, which couples economic development and environmental quality, comes very close to requiring an affirmative answer. If that were in fact the case, then it would mean that hard choices among alternative human aspirations would be decided within an inclusive ethical system. Environmental values would contend with truth, justice, faith, and compassion. It's a tough league.

In passing, I will say that it is difficult to get even as far as first base in this league. I have followed the attempt of my own Presbyterian denomination to deal with environmental values, and I regard it at best as a soft ground ball. The tendency, one that I suspect is not confined to our reformed tradition, is simply to choose sides in ongoing environmental disputes. The result is to add some political heat, but not much ethical light, to the debate.

To set the stage for my last question, suppose for the sake of argument that the answers to both of the previous ones is yes.

A global, open, market-driven society confers primacy on individual choice; if the result of such choice is some degree of environmental degradation, this is hardly reason to prefer an alternate form of social organization.

Imagine that the world is one of open and democratic political institutions, free and global markets, and inclusive value systems. Then the question is this: Are we prepared to live with the results? By "we," in this case, I mean anyone who thinks that sustainable development is important.

Before rushing to judgment on this one, consider the reaction to Paul Portney and Alan Krupnick's analysis of Southern California's new smog control plan. They were roundly attacked as immoral by folks who sincerely believe that the benefits of clean air are precious indeed. That these folks are self-selected from a limited set of the population that writes letters to the editor of *Science* may, of course, skew the responses somewhat, but let that pass. In any case, Portney and Krupnick responded by pointing out that there are other benefits that all this money could buy—neonatal care, nurture of the homeless, and accelerated AIDS research, to name a few. In other words, in a broader view of the human condition—one set in a more inclusive value system, if you will—buying the maximum amount of environmental protection may not strike the right balance among the needs of humanity.

This specific case is intended to illustrate the implications for the environmental community that the questions I have asked seem to present. That is to say, the very nature of a global, open, market-driven society confers primacy on individual choice, and this may discomfort persons who particularly prize environmental values. Should we, for example, simply grin and bear it when, say, a developing nation chooses priorities different from our own? Individual choice means that a nation can determine for itself the value of its endowment of natural and environmental resources. And a poor or newly free nation may be willing to trade a bit of environmental quality for enhanced economic growth or the accelerated development of democratic political institutions.

Even more uncomfortable is the possibility that the developing country in question may put an issue like climate change at the bottom of its priority list. This complication extends the discomfort beyond the "grin-and-bear-it" level, because we—that is, we rich folks—worry a lot about climate change. And since we will foot most of the bill to do something about it, we face a choice between imposing our values as a condition of our financial assistance, or, in the alternative, acceding to the recipient's priorities. In fact, it is precisely this choice that is plaguing the preparations for the United Nations Conference on Environment and Development in Rio de Janeiro in June.

Still, if all of these choices are fully informed and freely made, it is hard to quibble with the outcome. In particular, that the result may be a degree of environmental degradation that some would deplore seems to me hardly reason enough to prefer an alternate form of social organization. Others might disagree. Barry Commoner, in his book *Making Peace with the Planet*, argues that capitalism should not be entrusted with selecting socially acceptable means of production. And Pat Buchanan was recently quoted as being "slightly skeptical of democracy as a solution to all our problems." (I can't help but reflect that getting Commoner and Buchanan on the same side of an issue is at least as interesting as pairing Churchill and the pope.)

So much for my exercise in desktop publishing. I don't pretend to have the answers to the questions I have posed, even if I have the questions themselves right. Yet it is hard to escape the feeling that the political, economic, and ethical setting in which we pursue sustainable development will importantly determine whether we can succeed. Maybe that's why I have long suspected that the special stack of papers on my desk really are important.

Robert W. Fri is president of and a senior fellow at RFF. The preceding remarks were made at the Defining Sustainable Forestry Workshop in Reston, Virginia, on January 14, 1992.

Correction

An error appears in the article entitled "Environmental costing and electric utility planning and investment," by Karen L. Palmer and Alan J. Krupnick, in the Fall 1991 issue of *Resources*. The ratios of social cost to private cost reported in the last full paragraph on page 3 of the article are incorrect due to a calculation error. These ratios should be changed to read, in the order in which they appear in the text, 1.2, 1.3, 1.8, 2.6 (for damage-based costs) and 1.7, 1.9, 2.4, 8.4 (for abatement-based costs).

INSIDE RFF NEWS AND PUBLICATIONS

Joseph L. Fisher, 1914–1992

Joseph L. Fisher, president of Resources for the Future from 1959 to 1974, died on February 19. An economist, he served on the staff of the Council of Economic Advisers in the Truman administration before coming to RFF. He left RFF after his election to the U.S. House of Representatives from Northern Virginia's Tenth Congressional District in 1974. Soon after entering Congress, Fisher was named to the House Ways and Means Committee, where he made a reputation for his work on taxation, energy, and budget policy. In 1982 he joined the cabinet of Governor Charles S. Robb as Virginia's secretary of human resources. After leaving that post, he taught political economy at George Mason University until his death.

Fisher was recently honored by RFF for his leadership in initiating RFF's longstanding interest in the support of graduate training in resource and environmental economics. On January 13, RFF president Robert W. Fri announced the inauguration of the Joseph L. Fisher Dissertation Award. Formerly known as RFF's Dissertation Prize in Environmental and Resource Economics, the award will be given annually.

Edward S. Mason, 1899–1992

Edward S. Mason, a member of the board of directors of Resources for the Future from 1964 to 1969 and an honorary member since 1969, died on February 29. A professor of economics, he taught at Harvard University from 1923 to 1969 and was an assistant secretary of state for economic affairs in 1945. Over the years, he served as an adviser to the World Bank and many government agencies, including the Agency for International Development.

Joseph L. Fisher and Edward S. Mason: an appreciation

The deaths of Joseph Fisher and Edward Mason in late February have removed two men who were intimately connected with Resources for the Future. Joseph Fisher became associate director of RFF in late 1953. Edward Mason joined RFF's board of directors in 1964 and served on it until he became an honorary director in 1969.

When RFF's first president, Reuben Gustavson, retired in 1959, Joe Fisher was the obvious choice to take on the presidency, a position he occupied until he resigned in 1973 to seek election to Congress for the Tenth Congressional District of Virginia—an office he held for three consecutive terms. Public service was Joe Fisher's hallmark. Whether on the local or federal levels, or in academia, religious pursuits, or environmental organizations, he found fulfillment in joining others to further the public good as he saw it. RFF can be proud that he chose to stay with it for fifteen years and made it his primary intellectual home. His knack for spotting and attracting talent, and holding it, combined with the genuine warmth in his relations with the staff, were major factors in putting RFF on the map, and the sharpness of his mind and sense of equity helped RFF gain its persistent reputation for excellence and objectivity. We mourn his passing as that of a leader, teacher, and friend.

Ed Mason's affiliation with RFF was a "natural," and the wonder is that it didn't happen sooner. He had been one of the five members who constituted President Truman's Materials Policy Commission (the Paley Commission), a body whose work established the charter and set the course for Resources for the Future as an organization. At that time he was also dean of Harvard's Graduate School of Public Administration, later to become the John F. Kennedy's School of Government. A Harvard-trained economist, like Fisher, Mason's term with the Paley Commission had given him an enduring interest in resource problems and especially their policy aspects. It is no exaggeration to say that once on the board of directors at RFF, RFF's staff, officers, and directors looked to him for guidance in matters of economics. They never came away empty-handed. Even after his retirement he rarely missed a board meeting, and his presence could always guarantee a sober assessment of RFF's research activities. Ageing only sharpened his insights. He was one year older than the century when he died.

Hans H. Landsberg

New books

Global Development and the Environment: Perspectives on Sustainability,
edited by Joel Darmstadter

This collection of essays brings to bear past and current research from Resources for the Future on issues under consideration at the United Nations Conference on Environment and Development (UNCED) in Rio de Janeiro in June 1992. The conference is the outcome of a UN resolution that identifies a number of global problems—among them threats to atmospheric integrity, biodiversity, and human health—whose solutions require strengthened international attention and cooperation. The essays in this book examine some of the enduring questions that cannot be ignored in any international endeavors to resolve these problems. They are united under the theme of sustainable development in an introductory essay by RFF president Robert W. Fri, who observes that UNCED explicitly recognizes the link between environmental protection and economic development.

To set the stage for considering the conditions for sustainable development, the first essay considers the issue of population growth and the second explores salient elements of the concept of sustainability. Subsequent essays examine specific themes of concern at UNCED. These are the role of natural assets in economic development; the use of benefit-cost analysis in prioritizing environmental problems; sustainability in agriculture; the management of water for economic, environmental, and human health; energy transitions; climate variability and development; and the preservation of biodiversity as a resource.

These essays initially appeared as articles in the Winter 1992 issue of *Resources*, from which the foreword and preface have also been adapted. All but one were written by researchers at RFF.

February 1992. 92 pages. $9.95 paper. 0-915707-63-2

Mineral Wealth and Economic Development,
edited by John E. Tilton

This collection of papers—originally prepared for the 1989 John M. Olin Distinguished Lectureship Series on Mineral Wealth and Economic Development at the Colorado School of Mines—together with an overview by editor John E. Tilton, explores why domestic mineral wealth has not led to economic development in low-income mineral-exporting countries, many of which have suffered a drastic decline in per capita income over the past several decades.

As Tilton notes in his overview, three critical considerations influence the extent to which mineral resources promote or inhibit economic development. First, mineral wealth that remains in the ground is a dormant asset. Second, rents from mining and mineral processing must be invested, and invested wisely, to enhance the future flow of goods and services in the mining country. Third, nonrent effects from mining and mineral processing—for example, job creation and worker training—are not always beneficial to a mining country's economy and under some circumstances can inhibit economic growth.

Concluding that domestic mineral wealth need not retard growth and development in low-income mineral-exporting countries, contributors to the volume, all of whom are recognized experts in minerals economics, offer advice to public officials striving to turn their countries' mineral resources into assets. They recommend that these resources be exploited rather than held in reserve, that public policy be created to maximize mineral rents flowing to the host country, and that the adverse effects of mineral exploitation caused by the instability of commodity markets be minimized and the benefits be maximized.

February 1992. 129 pages. $22.50 paper. 0-915707-62-4

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