Chapter 7

Increasing Our Knowledge of the Environment

Behind the rising prosperity in the developing world lurks the shadow of lethal air pollution from motor vehicles, smokestacks, and hearths. All these sources and others emit tiny airborne particles that lodge deep in the lungs, causing severe and sometimes fatal respiratory problems. Every year in four Chinese cities alone—Chongqing, Beijing, Shanghai, and Shenyang—10,000 people die prematurely from exposure to these particles. And throughout the developing world such pollution kills hundreds of thousands of people and seriously damages the health of millions more. Workdays lost to respiratory illness run into the hundreds of millions and the corresponding economic costs into the billions of dollars.

These losses were once viewed as the price of economic development. Fortunately, the countries that have pioneered environmental protection in the developing world have shown this view to be gravely mistaken. Operating in very different political and institutional cultures, they have used pollution charges, grassroots community pressure, and command-and-control regulation to contain or even roll back air pollution at supportable cost. Across their diverse approaches lies an important unifying factor: the global community's accumulation and dissemination of knowledge—knowledge about measuring air quality, about evaluating health risks, about identifying pollution sources, about estimating abatement costs, about setting enforcement priorities, and about designing cost-effective regulatory instruments. As knowledge has accumulated and environmental policy strengthened, air quality has stabilized and even improved in many rapidly industrializing areas.

What is true for air pollution is true for many other types of environmental damage. Each year, diarrheal diseases from contaminated water kill about 2 million children and cause 900 million episodes of illness, most of which oral rehydration therapy and basic sanitation could have prevented. Annual losses from soil erosion range from 0.5 to 1.5 percent of GNP in many countries, but well-informed policies can trim these costs substantially. Greenhouse gas emissions will double within a generation at current growth rates, but effective policies and dissemination of information can greatly reduce them.

There is now general agreement about the importance of limiting environmental damage. We also have a good understanding of why government action is needed to preserve the environment. For example, pollution has adverse effects on others, but the polluter typically does not have to compensate them. When such spillover effects, or externalities, occur, the cost of pollution to society is greater than the cost to the polluter. There is then too much pollution because individuals and firms do not have the right incentives to reduce it. A factory that discharges pollutants into a river has no incentive to consider the damage inflicted on those downstream. A user of freon-based air conditioning has no incentive to take account of the damage freon causes to the atmosphere's ozone layer. Drivers have no incentive to reduce exhausts and improve air quality for their neighbors.

Effective public policies provide incentives to reduce pollution and natural resource degradation by aligning social and private costs. In some cases, legal systems can produce such alignment without direct government action. For instance, laws in some countries require polluters to compensate others for certain kinds of pollution damage. The assignment of property rights can also reduce the scope for environmental degradation; for example, a lake that has one owner is not likely to be overfished. But the holders of those rights may incur large transactions costs in enforcing them, and the assignment of property rights sometimes is simply not feasible—who, for example, should own the atmosphere?

Problems such as these have forced governments to do more to protect the environment. In some cases government regulators can give polluters the right incentive to clean up by charging them for the damage their activities cause. When information on discharges or the extent of their damage is not available, systems that monitor the more easily observable actions of polluters, such as the required installation of pollution control devices, may be desirable. With the right information, however, pollution charges are superior. Unlike technology standards, they put firms under continuous pressure to reduce pollution.

Information can also encourage pollution reduction. A government's regulations (including pollution charges) apply across its whole jurisdiction and may not be appropriate for all areas—environmental, social, and economic conditions may differ. In such cases, public disclosure of a polluter's emissions can complement formal regulation. Informed consumers may then buy fewer products from heavily polluting firms. Investors concerned about liability may become reluctant to finance them. And neighboring communities may insist that they improve their environmental performance.

Disseminating information on the implications of environmental degradation can also offer opportunities for improvement, but the impact of better information depends on people's ability and willingness to use it. That returns us to this Report's two main themes: narrowing knowledge gaps and addressing information problems.

This chapter discusses two main issues:

- *The importance of knowledge and information for environmental management*. Better environmental outcomes require more knowledge about environmental impacts and about technologies, as well as information about environmental performance such as the pollution generated by particular polluters.
- *The design of appropriate institutions for environmental management.* Effective management requires knowledge about the impact of alternative institutional arrangements, their information requirements, and the circumstances in which they will work well.

Knowledge for environmental management

The analysis of environmental degradation often centers on its relationship to economic development. Some argue that such degradation is the inevitable by-product of social and economic development, at least in its initial stages. Others argue that economic and social development will not suffer in the long run if natural resources are properly managed. Thus some see environmental management as a complement to development; others see the two as conflicting. But severe environmental degradation can occur even without development, simply from population pressure. This Report endorses a balanced view: good policies can support sustainable development strategies by protecting and even improving the environment while promoting economic growth. Such strategies call for good institutions, appropriate incentives, good information, and better knowledge of the environmental impacts of alternative policies.

The key aspects of the long, knowledge-intensive process of integrating environmental management with development are the following:

- *Understanding the environment and the processes that affect it* by identifying the sources of environmental degradation, its consequences, and the costs of reducing it, as the foundation for effective policy
- *Developing indicators of environmental performance* that policymakers at the local, regional, and national level can use
- *Using environmental information* to improve both public regulation and private decisionmaking, and
- *Managing environmental knowledge* by building the capacity to gather and disseminate knowledge, improving private sector environmental management, and broadening public policy models to include environmental variables.

Understanding the environment

We rely on markets to ensure the efficient supply of most goods and services. Prices determined by the intersection of demand and supply usually provide all the relevant information for efficient resource allocation, including the additional (marginal) benefit to consumers and to producers of an additional unit of output. The marvel of the price system is that no central planner has to know the details of consumers' preferences or firms' technological possibilities. But for the supply of clean air, clean water, and other environmental goods things are different. Such goods are not exchanged in markets. There are no prices to reflect consumers' marginal valuation of cleaner air or water or the cost to producers of providing them.

A collective decision must accordingly be made about how clean the environment should be. Different individuals may have different views, however, and these views have to be reconciled through the political process. To reach agreement, people have to know the consequences of different levels of pollution. Such knowledge is thus an essential part of decisions about environmental policy, but it can never be perfect. Consider, for example, the uncertainty about the impact of different levels of particulate air pollution on the health of different groups of people, including asthmatic children.

Under some conditions, society can use available knowledge to develop the system of environmental prices that the market has failed to create. Such prices, imposed on polluters in the form of pollution charges, are based on a collective decision about the marginal social cost of pollution. Appropriate pollution charges force polluters to pay that marginal social cost. This provides the correct incentive for producers to operate efficiently, by aligning the marginal social benefits with the marginal social costs. Once collective preferences are determined, such environmental prices work much as do prices for other goods.

But often the marginal social cost of pollution depends on the level of pollution. The appropriate charge cannot be determined until one knows what level of pollution will emerge, and that cannot be predicted without certain technical knowledge. Even then, there is likely to be considerable uncertainty, with adjustments having to be made over time. If pollution increases to a level higher than anticipated, the price charged for it may have to be increased. That is why monitoring levels of pollution is essential.

It might also prove impossible to levy charges on each firm or household that reflect its true contribution to pollution. That would require monitoring at the household or the firm level, which might be costly. Often, therefore, government action to protect the environment takes the form of regulation affecting pollution more directly. Cars may be limited to emissions below a certain level; coal-burning power plants may be required to install scrubbers that reduce sulfur dioxide emissions. For policies to be efficient, regulators must know the marginal costs associated with these tighter standards, to compare them with the marginal social benefits of pollution abatement. But such information can be difficult and expensive to acquire.

Incomplete information and knowledge also pose major problems for natural resource conservation. Data on environmental variables are often scarce and inadequate. And given the complexity of many ecological processes, translating environmental data into knowledge is difficult.

Some links between human activity and ecosystems are far from obvious. In Malaysia in the 1970s, supplies of the durian fruit began mysteriously to decline, threatening a $100-million-a-year industry. The durian trees were intact and apparently healthy, but were bearing less fruit. Then it was discovered that the flower of the durian tree was pollinated by a single species of bat, whose population was falling because of a decline in its primary source of food: flowering trees in mangrove swamps, which were being converted to shrimp farming.

In other instances, tackling the long-term effects of policies with environmental impacts requires sustained investment in monitoring and in updating knowledge. As discussed in the Overview, the green revolution has brought dramatic increases in agricultural yields, with beneficial effects on food security, farm income, and poverty alleviation. But concerns about the long-run environmental impact of the green revolution highlight the need for more knowledge.

Experience from Pakistan illustrates these concerns. In 1970 the success of the first generation of high-yielding varieties and the wider availability of irrigation led to predictions that Pakistan would soon become a net exporter of grain. For the next two decades, however, deficits in the domestic production of wheat—the major food staple—persisted, requiring imports of at least a million tons every other year. Consensus is still lacking on the causes of this disappointing performance, and it is certainly possible that they have nothing to do with natural resource degradation. Further observation and analysis will be needed to determine whether the benefits of high-yielding varieties were at least partly offset by accompanying nutrient depletion, soil compaction, declining soil organic matter, and widespread diffusion of specialized, potentially disease-prone cropping systems. But the findings of a recent study are at least cautionary: average production costs rose by 0.36 percent per year in one post–green revolution decade (1984–94), and degraded resources (especially soil) correlate with higher costs.

Knowledge takes time to evolve, be disseminated, and be accepted. Progress often occurs in bursts, first in the scientific community and eventually in society at large (Box 7.1). And political processes matter as much as scientific progress. The development community has been slow in fully accounting for the social and environmental consequences of large hydropower and forestry projects, for example. Increasingly, such accounting has been understood to be highly knowledge-intensive, requiring the participation of many stakeholders.

Knowledge can also be lost. For a long time indigenous knowledge was enough to guide environmental management. Traditional farming in Africa and Latin America, based on shifting agriculture, was efficient in managing nutrient cycles and regenerating soil fertility. But demographic pressure and commercial incentives favoring the mass planting of single crops displaced more diversified, subsistence-oriented systems, putting the survival of that knowledge—and the associated environmental control mechanisms—in jeopardy. Local and traditional knowledge is now used more extensively in the design of systems for the collection and analysis of information and in the promotion of sustainable farming practices.

Decisions on natural resource use, besides having spillover effects on current generations, may also affect future generations—a fact at the core of thinking about sustain-

Box 7.1

The slow evolution of knowledge about climate change

1824 Jean Baptiste Fourier first describes the natural greenhouse effect, comparing the action of the atmosphere to that of glass covering a container.

1850–70 The industrial revolution intensifies, starting a process of steadily growing greenhouse gas emissions.

1896, 1903, 1908 In three articles the Swedish scientist Svante Arrhenius hypothesizes that burning coal will increase the atmospheric concentration of carbon dioxide and warm the earth. He suggests that warming may be desirable.

1958 Continuous monitoring of carbon dioxide concentrations in the atmosphere begins at the Mauna Loa Observatory in Hawaii and at the South Pole.

1965 The U.S. President's Science Advisory Committee includes a chapter on atmospheric carbon dioxide in its report on environmental problems.

Early 1970s Widespread concern develops over potential global climatic cooling induced by industrial and agricultural aerosols.

1979 The first World Climate Conference is held in Geneva. Concern about global warming is revived, but the conference statement is cautious about the issue.

1985–87 International meetings in Villach, Austria, and Bellagio, Italy, establish climate change as an international concern.

1988 An international group of scientific experts is organized as the Intergovernmental Panel on Climate Change (IPCC).

1990 The Second World Climate Conference in Geneva presents the results of the first IPCC assessment report. The IPCC estimates that a 60 percent cut in emissions would be needed to stabilize atmospheric carbon dioxide at the 1990 level, but no conclusive link between human activity and global warming is established.

1992 The United Nations Framework Convention on Climate Change is signed in Rio de Janeiro by more than 160 nations. The convention includes nominal objectives for some countries but no binding targets.

1995 The IPCC publishes its second assessment report, concluding that "the balance of evidence suggests that there is now a discernible human influence on the global climate."

1997 Agreement is reached on the Kyoto Protocol. Industrial countries and most of the economies in transition from central planning commit themselves to reducing greenhouse gas emissions by an average of 5.2 percent below 1990 levels in the period 2008–12.

able development. Thus sustainable development involves generating information about the spillover effects of current decisions across space and over time. It also means putting in place incentive systems that induce stakeholders to take that information into account.

According to a common interpretation of sustainable development, future generations will be no worse off than today's if they have at least an equivalent overall resource base consisting of a mix of natural, infrastructural, and knowledge capital. Some natural resources can be safely depleted, in this view, if the proceeds from their extraction are invested in the accumulation of other forms of productive capital. If human capital can substitute for natural resources, for example, a country may choose to reduce its stock of forested areas to invest the returns from logging in higher education.

But substitution is not always possible. To what extent can human-made capital (including knowledge) replace natural capital? Answering this question requires knowledge about some critical tradeoffs. Since such knowledge is still scarce, some strongly conflicting views are held. Some argue that opportunities for substitution are ample, others that substitution possibilities may be severely limited by poorly understood ecological thresholds. They caution against policies with potentially irreversible effects, such as conversion of wetlands or forests and the loss of watershed protection and microclimate regulation. If the effects of a development decision are irreversible—or reversible only at very high social cost—a more cautious exploitation of natural resources may be called for than in conditions of full certainty or in the absence of irreversibility (Box 7.2).

Simply knowing the long-term effects of environmental problems—and the risks and limits of technological fixes—is not enough to ensure sustainability. Even with this knowledge, countries may lack the political incentives to implement market or institutional reforms. Political institutions are geared to the short term, and long-term programs are often difficult to implement, especially if they are costly or make powerful and vocal interest groups worse off. Overcoming this lack of institutional foresight is a key challenge for sustainable development.

Further problems can arise from environmental impacts that cross regional or national boundaries. Sulfur dioxide from power plants in the midwestern United States may bring acid rain to eastern states. Farmers in developing countries who clear forested land for subsistence agriculture have no incentive to take global impacts into account, whether or not they are aware of their contribution to global habitat loss and higher concentrations of atmospheric carbon dioxide. In these cases efficiency requires that environmental protection be undertaken within a broader political jurisdiction.

When the impacts are global, action has to be international. In recent years the international community has adopted a variety of conventions that seek to improve the global environment. At one extreme, the Montreal Protocol on ozone-depleting substances targets a specific problem and imposes a clearly defined schedule for action. It has been judged largely successful, possibly because of its specific focus and because of widespread agreement about the risks associated with ozone depletion. At the other extreme, Agenda 21, adopted by the 1992 Rio Earth Summit, includes an extremely broad set of environmental objectives but no common action plan. It is hard to identify particular successes for such a broad agenda, although it may well have contributed to international awareness of environmental problems.

Developing environmental performance indicators

Monitoring environmental quality is essential for environmental management. But our perception of environmental performance—and its effect on human welfare—depends on the framework in which this information is presented. The standard way of organizing country data on wealth and performance is the system of national accounts. But national accounts are geared toward macroeconomic management and are less suitable for assessing social welfare more broadly. Since they do not reflect depletion and degradation of the environment, they may give false policy signals to countries aiming for environmentally sustainable development. To monitor environmental quality, a different information framework with additional indicators is needed.

The most effective indicators are aggregates that summarize the underlying data to aid in diagnosing environmental problems. Equally important for policy are performance indicators: how have key aspects of environmental quality responded to the policy prescriptions applied? Some indicators measure environmental goods, such as the extent of protected lands or biodiversity. Others measure environmental bads, such as excess logging, soil loss, or air and water pollution. Still others monitor the effects of environmental degradation, such as the incidence of waterborne disease or species loss.

Environmental indicators need to present a coherent picture of the links between human activity and the environment. The OECD's pressure-state-response framework (Figure 7.1), the basis of almost all systems of environmental indicators, provides such coherence. The framework recognizes that indicators of both cause (pressure on the environment) and effect (the state of the environment) are needed to manage complex systems, as are response indicators to track policies and behavioral changes that mitigate environmental impacts. Within this framework,

Box 7.2

Uncertainty, irreversibility, and the value of information

The choice between conserving and developing natural resources is often rendered difficult by uneven information. Returns from development decisions (say, to convert a forest to industrial use) are known with a reasonable degree of confidence, whereas the benefits of conservation (say, the possibility of discovering valuable genetic resources or developing ecological tourism in a wilderness area) tend to be uncertain. But by forgoing immediate development, land managers leave open the option of acquiring better information on the comparative returns from alternative land uses.

Option value is defined as the expected value of future information from or about resources under conservation. Typically, option value is positive, which implies a gain from the decision to postpone development until more information is available on the benefits from conservation. Although its counterfactual nature makes the measurement of option value difficult, approximations have been attempted in a few cases.

In the late 1970s a previously unknown variety of teosinte, a wild relative of maize, was found in the remote Sierra de Manantlán region in Mexico. Besides being disease resistant, the newfound plant variety offers the potential for developing a breed of perennial maize. If adopted on a large scale, perennial maize could significantly lower the labor and capital costs of production—and thus the price of maize.

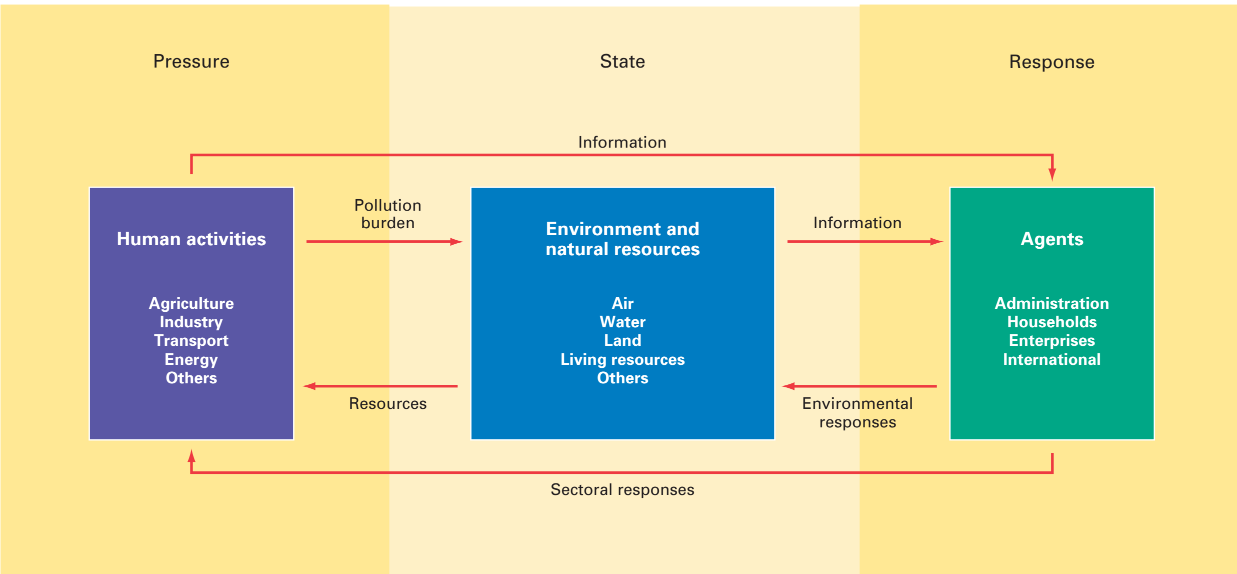
This episode offers an interesting opportunity for applying the concept of option value with the benefit of hindsight. Had the wilderness area been converted to development, the new variety of teosinte might never have been found, and the possibility of developing a commercially viable variety of perennial maize would have been lost. But by preserving the wilderness, land managers decided to forgo possible development benefits—and serendipitously reaped conservation benefits instead.

Based on estimates of U.S. demand and supply for maize and on plausible assumptions about the returns from development of the wilderness area, the option value of conserving the wilderness area has been estimated at around $320 million. A short-sighted decisionmaker would have chosen to develop the area, whereas a more cautious land manager would have waited until more information was available on the benefits from conservation. The second choice would have been the right one, unless the immediate benefits from development exceeded $320 million.

Figure 7.1

The pressure-state-response framework

Monitoring environmental performance takes a sophisticated model of how society and nature interact.



Source: OECD 1994.

well-structured sets of physical indicators can be constructed to inform both decisionmakers and the public about environmental change.

The need to better capture environmental degradation in national accounts has given rise to the concept of green national accounting, or "green GNP." Green accounting is intended to correct the national accounts by subtracting from GNP the costs associated with natural resource depletion and pollution damage. There is widespread agreement that such adjustments are conceptually appropriate. But the necessary supporting knowledge is often lacking. Estimation and valuation of environmental impacts remain more art than science in many cases; thus suggestions for adjustments to the national accounts have varied widely. Despite the many uncertainties, some countries have begun incorporating estimates of green GNP into policymaking. Among developing countries, the Philippines has one of the most advanced systems of green national accounts.

A sibling of green national accounting, genuine saving, has also been put forward as a direct indicator of whether a country is on a sustainable path. It measures the rate at which wealth is being created or destroyed—the true saving rate after accounting for investments in human capital, depreciation of produced assets, and depletion and degradation of the environment. Negative genuine saving implies that total wealth is in decline. Policies leading to persistently negative genuine saving are policies for unsustainability.

Genuine saving departs from standard national accounting in several ways. It deducts from output values the value of the natural resources used up in producing that output. Deducting pollution damages—including lost welfare in human sickness and death—is also appropriate if society aims to maximize welfare, not just consumption of goods and services. And in recognition of the role of knowledge in accumulating wealth, estimates of genuine saving consider current education spending as an increase in saving, not in consumption as in traditional national accounts.

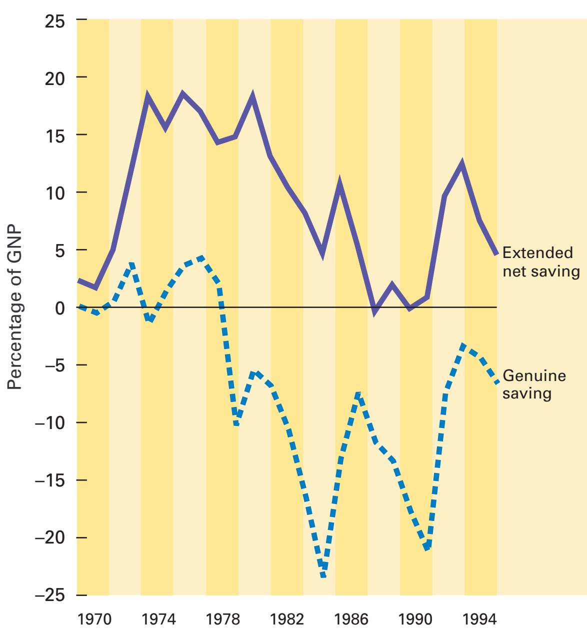
Genuine saving rates reveal whether countries are living off their capital stock, and many are: these rates have been negative in some countries for extended periods (Figure 7.2). In Ecuador genuine saving has been near zero or negative for much of the period the country has been exploiting its oil reserves. And the "lost decade" of the 1980s was characterized by negative genuine saving for many other countries in Latin America and the Caribbean. Genuine saving rates in Sub-Saharan Africa deteriorated sharply in the late 1970s and have been negative ever since, except in 1980 (Figure 7.3).

Genuine saving makes the growth-environment tradeoff explicit, since countries planning to grow today and protect the environment tomorrow will exhibit depressed rates of genuine saving. Its role is to alert policymakers to unsustainable practices and trends. But responding to this signal requires more: it takes a broad understanding of environment-economy links at the macroeconomic, sectoral, and project levels; it also takes sound policy design and skillful environmental management. In Botswana, for example, natural resource accounts are a key instrument for developing public expenditure policy. The authorities recognize the value of resources and the importance of reinvesting resource rents. This understanding has led to better macroeconomic and environmental performance.

Figure 7.2

Genuine saving in Ecuador

Genuine saving—a measure that accounts for environmental losses—can fall well below conventional measures of saving.

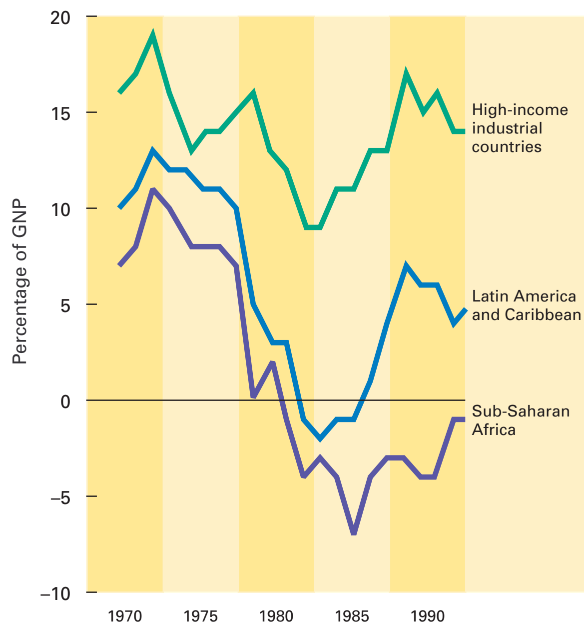


Note: Genuine saving is extended net saving adjusted for resource depletion and global environmental damage. Extended net saving is extended domestic investment (gross domestic investment plus expenditure on education) minus depreciation and foreign borrowing. Source: World Bank 1997c.

Figure 7.3

Genuine saving in selected world regions

Genuine saving has been low and sometimes negative in many developing countries.



Note: Genuine saving is defined as in Figure 7.2. Source: World Bank 1997c.

Using environmental information

Recent evidence suggests a strong relationship between environmental regulation and economic development. *World Development Report 1992: Development and the Environment* argued that developing countries have plenty of opportunities to implement sustainable development policies. The efficient generation, dissemination, and use of knowledge—on the costs of inaction and on the benefits of environmental improvements—are keys to formulating and implementing these policies.

The information generated through monitoring the state of the environment can be used in several ways. First, it helps regulators determine whether to tighten or loosen environmental standards. For instance, some pollutants may have threshold concentrations, beyond which the risks of cancer or respiratory illness jump from negligible to significant. It is important to know whether the concentrations of such pollutants are nearing critical thresholds. Second, although pollution control is most effective when pollution from firms and households is directly monitored, a second-best approach is to monitor their pollution control activities. For example, pollution control devices on automobiles can be observed and tested, even if it is not practical to monitor emissions from each vehicle.

In some cases firms and households may respond directly to information about their polluting activities. Many do not want to contribute to environmental degradation, and they will respond as good citizens to information about the environmental consequences of their activities. Community groups, industry associations, and resource user associations can exert peer pressure on their members to act responsibly. But information alone does not provide a sufficient guide to action for individuals, firms, or their associations. Government regulation and penalties provide important incentives for adjusting pollution to socially sanctioned levels. Incentives may also be provided through pressure exerted by one interest group upon another: disseminating information about pollution by different firms can generate strong community pressure on them to reduce pollution, for example. In Indonesia, environmental regulators have significantly reduced water pollution by developing and publishing ratings of polluters' environmental performance (Box 7.3).

Care must be exercised, however, in using public disclosure as a tool for environmental regulation. The public may need help in interpreting the information, because the risks associated with different pollutants are not commonly known. Indonesia's ratings are developed from benchmark standards that reflect national pollution regulations; a poor rating informs the public that a firm is not in compliance with national environmental standards.

But in the United States and other OECD countries, such public disclosure programs as the Toxics Release Inventory have disseminated raw information on toxic emissions with no interpretation or risk assessment. Some chemicals labeled toxic in these programs are indeed quite dangerous, even in small doses. Others would be hazardous only after long exposure at very high levels. By treating all chemicals the same, such disclosure programs may alarm the public unnecessarily and pressure industry into adopting high-cost abatement programs that would yield few social benefits. In recent years, academic researchers and NGOs have enhanced the value of such disclosure programs by focusing public attention on the relative risks of different chemicals.

Sometimes firms themselves are in the best position to assess the environmental risks of their activities. In such cases it is reasonable to impose legal liability for pollution damage and for cleanup of toxic waste sites. But because many small firms do not have the capacity to judge the environmental impact of their emissions, legal liability cannot be imposed in all circumstances. Governments are often better positioned than firms to judge risk. Indeed, as governments have assumed more responsibility for environmental regulation, many firms have naturally come to assume that unregulated activities are not harmful.

Box 7.3

Public information for pollution control in Indonesia

The traditional approach to environmental regulation—through permits, monitoring, and enforcement—has often been slow, contentious, and costly, even in industrial countries. As a result, industrial and developing countries alike are trying new approaches to more effective pollution regulation. Indonesia's Program for Pollution Control, Evaluation, and Rating (PROPER), launched in 1995, is one such approach, which shows that local communities and market forces can be powerful allies in the struggle against industrial pollution.

PROPER was a response to a serious risk of water pollution damage due to weak formal regulatory enforcement accompanied by rapidly growing industry. Under the program a factory is assigned a color rating based on the government's evaluation of its environmental performance. A blue rating is given to factories in compliance with regulatory standards, and green to those whose emissions controls significantly exceed standards; the gold rating (yet to be awarded to any firm) is for world-class performers. Factories that fall somewhat short of compliance receive a red rating, and black is for those that have made no effort to control pollution and have caused serious environmental damage.

Armed with this information, local communities can negotiate emissions controls with neighboring factories, firms with good performance can earn goodwill in the market, investors can more accurately assess firms' environmental liabilities, and regulators can focus their limited resources on the worst offenders. During its first two years in operation, PROPER proved quite effective in moving poor performers toward compliance. More than 30 percent of the first 187 factories rated moved from red or black to blue status in 15 months. Some 400 factories are currently in the system, and Indonesia plans to extend coverage to 2,000 polluters by the year 2000. Inspired by these and other examples of public information in action, Colombia, Mexico, and the Philippines are starting their own public disclosure programs.

As relevant scientific data accumulate, knowledge about the environment and about complex economy-environment interactions is steadily improving. Better understanding of these interactions is essential for identifying environmental risk and efficiently managing natural resources. But nature is complex: some ecosystems may suffer irreversible damage after degradation has passed critical thresholds. Solid scientific results are still very scarce, and so any decisions about the environment are filled with uncertainty.

Better information can open new opportunities—and prevent costly mistakes—by allowing fine tuning of responses to environmental risk. The value of this information is then the net welfare gain from fine tuning. For climate change it has been estimated that resolving only some of the key uncertainties could be worth billions of dollars.

Better understanding of weather patterns also has value. Consider a farmer's decision about which crops to plant and when to plant them for next season's harvest. Among other factors, the choice depends on the weather pattern expected over the coming months. Therefore more reliable weather forecasts should provide significant benefits to farmers. Agricultural yields in parts of Latin America and Africa have been highly correlated with El Niño–Southern Oscillation (ENSO) events (Figure 7.4). Without reliable forecasts, farmers are forced to make planting decisions that are correct for an average season, and take the risk of serious damage from an unforeseen extreme weather event. With a better understanding of ENSO events and the ability to forecast them, farmers can receive long-term weather forecasts before they make their planting decisions. This should reduce the correlation between ENSO events and yields, and thus the incidence of ENSO-related famines.

The weather anomalies surrounding the 1997–98 El Niño also show the difficulty of understanding complex natural phenomena. Although scientists can now forecast weather patterns in an El Niño year with some confidence, they are often surprised by the magnitude of weather anomalies and their strong links with other phenomena. The intensity of recent forest fires in Southeast Asia—caused by human activity but aggravated by the dry conditions from El Niño—took many by surprise.

Another way of using environmental information is in the design of new technologies. Technological advance is often itself a major cause of environmental problems, but technological progress and innovation can also be part of the solution. Stimulated by environmental regulations that provide appropriate incentives, the supply of environmentally friendly technologies is expanding:

- Modern computer mapping systems can monitor developments in the natural resource stock.
- Pollution abatement technologies—such as electrostatic precipitators or flue gas desulfurization—reduce air emissions from power generation.
- Equally important are substitution technologies, such as renewable energy sources or unleaded gasoline.

Even so, environmentally friendly technologies are undersupplied by the market, because (as discussed in Part One) the information they embody is a public good and because, as we have seen in this chapter, it is difficult to bring environmental benefits into the calculations of individual economic actors.

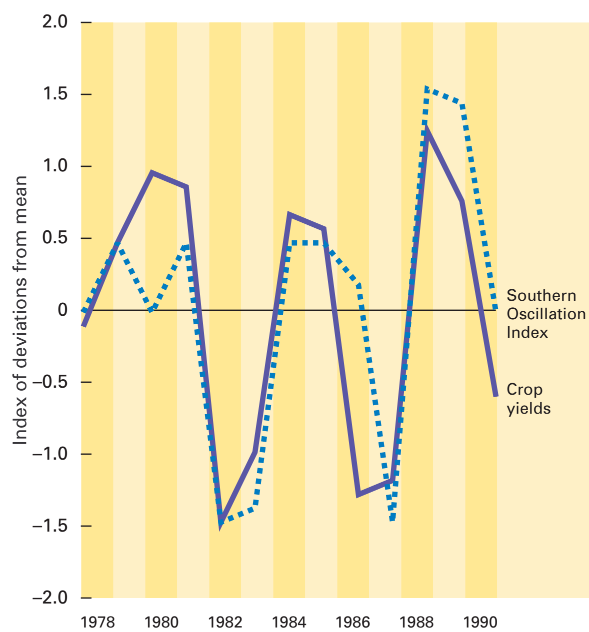
Moreover, reliance on technology to solve environmental problems is seldom enough. Ecological and chemical processes—and environment-economy links—are generally too complex to allow a simple technological fix. Often a solution to one environmental problem causes or aggravates another. Hydroelectric power, for example, is clean energy, causing no air pollution. But large dams and their reservoirs take up land, and if not carefully designed and sited can require the relocation of large numbers of people and damage ecosystems. Moreover, one technological alternative may not be a perfect substitute for the technique it seeks to replace. In the Republic of Yemen firewood is an important source of energy even in high-income urban households, because such alternatives as liquefied petroleum gas are considered inferior for the most important household use: baking bread.

Better knowledge about policy also makes an important contribution to environmental management. How do policies affect the environment? How can cost-effective policies be best designed? And how can tradeoffs between

Figure 7.4

Deviations from normal weather patterns and crop yields in Latin America

Better El Niño forecasts could be a boon to Latin America's farmers.



Note: The Southern Oscillation Index measures the direction and magnitude of the El Niño–Southern Oscillation; troughs mark El Niño events. Data are normalized deviations from annual averages. Underlying data for crop yields are from the Oaxaca Valles Centrales of Mexico. Source: Dilley 1997.

environmental and other objectives be assessed and responded to? For example, policymakers now realize that hidden subsidies in the sale of hydroelectric energy can lead to lower national income and diminished environmental quality.

With sophisticated knowledge management and decision support tools—and a better understanding of complex social and natural systems—policymakers are now implementing broader, more integrated approaches to environmental management. Coastal zone management and pest control in agriculture are good examples (Box 7.4). Such integrated approaches are knowledge-intensive, but they can often achieve a given objective more cheaply. At China's Waigaoqiao thermal power plant, an integrated approach to sulfur emissions in the plant's urban airshed saved $100 million in flue gas desulfurization equipment. By installing such equipment in an older, more polluting plant closer to the urban center rather than in the new power station in the outskirts, the same air quality benefit was achieved more cheaply. Recognizing the cost-effectiveness of the proposal, the municipality agreed to an exception to the regulations and approved the arrangement.

Box 7.4

Integrated pest management in Indonesia

Farming systems that rely on the intensive use of chemical pesticides are frequently held responsible for several negative environmental effects: direct public health risks, pesticide resistance, and soil and water contamination. Integrated pest management (IPM) is an environmentally sound alternative to pesticide use. It encourages natural control of pests by using natural enemies, planting pest-resistant crop varieties, adopting cultural management, and, as a last resort, judiciously using pesticides.

In Indonesia until 1986, recurrent infestations of the brown plant hopper, induced by indiscriminate insecticide use, threatened rice production. Research had shown that the pest could be kept under good biological control by indigenous predators. A 1986 presidential decree banned 57 insecticides for use on rice and called for massive efforts to train government field staff and farmers in IPM. This validation of the approach allowed further important policy changes: complete removal of pesticide subsidies within two years (saving the government $120 million a year) and implementation of a national IPM program.

In 1989 the Indonesian government initiated one of the most aggressive IPM programs ever, with support from the U.S. Agency for International Development, the Food and Agriculture Organization, and later the World Bank. An IPM training project was added in 1993 to support the national program. Its objective is to train 800,000 farmers and trainers and provide policy support to strengthen the regulatory and environmental management of pesticides.

By 1997 the project had trained more than 600,000 farmers, including about 21,000 farmer trainers. Trained farmers carry out their own field investigations while relying on local and traditional knowledge to adapt broad concepts and practices of IPM to local conditions. They use community mechanisms to diffuse knowledge and support the adoption of IPM practices by other farmers.

IPM is an information-intensive technology that needs continuous inputs from research and other sources to maintain its dynamism at the farm level. And there are many more actors now: local governments, farmer groups, NGOs, and donors. The challenge is to ensure that farmers remain focused on the problem, through farmer-to-farmer extension, organizing farmer associations, developing informative media, and fostering participatory planning and implementation.

Managing environmental knowledge

Managing environmental knowledge, disseminating it, and building capacity for its efficient use are at least as important as creating such knowledge. That is why more environmental projects now include information systems and capacity building. The West African Newsmedia and Development Center, a regional NGO based in Benin, is targeting the media as a cost-effective means of disseminating environmental and development information. It has successfully built local capacity and integrated environmental issues into reporting by both print and broadcast media.

Better environmental management also requires creating appropriate incentives, for example by removing market distortions, resolving policy and information failures, and establishing compensation mechanisms where appropriate for those who lose from these changes. Given the right incentives and the ability to process relevant information, people will start exploiting opportunities that benefit both them and the environment. Ample evidence shows that this works for households, firms, and public entities. Mexico's Guadalajara Environmental Management Systems Pilot shows the power of managing environmental knowledge in the private sector (Box 7.5).

Data on the state and quality of the environment, even when incomplete, can be voluminous. Decisionmakers need tools and indicators that integrate and summarize data on environmental phenomena. Large, computer-based decision support tools can capture environment-economy links, to help decisionmakers set priorities and improve the design of response measures, for example by simulating the environmental consequences of different courses of action.

Consider such long-range pollutants as nitrogen oxides and sulfur dioxide. Their dispersion patterns are now reasonably well understood for many parts of the world, and information about the susceptibility of soils and species to acid deposits is gradually improving. This allows researchers to simulate the likely geographical distribution of environmental damage of emissions from different sources, and to compare deposits under different scenarios against critical loads—that is, the level of deposits beyond which ecosystems in an area would be seriously damaged (Figure 7.5).

Many environmental problems are caused by local market and policy imperfections but shared by countries worldwide, making the regional and global sharing of information important. For example, in Sub-Saharan Africa the Knowledge and Experience Resource Network supports local environmental planning and management in urban and rural communities. For preventing deforestation, networks of local centers collecting and analyzing information can be quite cost-effective (Box 7.6).

Building efficient environmental institutions

What is the best way to generate, transmit, and use environmental information—and to overcome the market imperfections that generally underlie environmental problems? Different institutional forms have different information requirements. For instance, market-based regulations that charge for emissions require monitoring of those emissions, which can be expensive and difficult. To set these charges appropriately, the government has to assess the marginal social cost of pollution—also difficult, even under the best conditions.

If the marginal social cost of pollution depends on the level of pollution, the information requirements are even greater. Either the government must have advance knowledge of the relationship between charges and resulting pollution levels before it sets the charge (which requires considerable information about technology), or it must be willing to adjust the charge if the resulting pollution varies from the desired level.

If the government issues tradable permits for pollution (Box 7.7), it must still monitor pollution levels. In addition, it must solve the difficult problem of distributing permits. This is an impediment to the use of tradable permits for pollution control.

Command-and-control regulation has a different set of information demands. Monitoring whether a particular technology is being used may be much easier than monitoring the level of pollution. But the choice of technology standards requires sophisticated knowledge of technologies—knowledge more likely to reside in regulated firms than in regulatory institutions. Different regulatory systems may also encounter different kinds of uncertainty. For instance, tradable permit systems may have little uncertainty about total emissions, but great uncertainty about the permit price that will be compatible with that level of emissions.

This section addresses the issue of informationally efficient mechanisms at four levels:

Box 7.5

Strengthening environmental management to boost performance

The Guadalajara Environmental Management Systems Pilot, begun in 1996, is helping 15 small and medium-size enterprises in that city implement an environmental management system based on an internationally known standard, ISO 14001. The standard does not set specific pollution control targets. Instead, it establishes the required elements of an effective environmental management system, including:

- An environmental policy, defined by top management and communicated throughout the organization
- Planning, including objectives and targets incorporated into a management program consistent with the environmental policy, defining responsibilities, resources, and a time frame
- Mechanisms for implementation of the environmental management program
- Procedures for monitoring and corrective action, and
- Periodic management review of the system, to ensure its continuing effectiveness.

Such systems do not just improve environmental management; they also appear to increase environmental performance. For many smaller firms the process has raised the environmental awareness and knowledge of all staff, from directors to production workers. In just a few months employees started to propose environmental improvements, and they were given the authority to implement them. Managers use the information thus generated as a marketing tool and to improve compliance with regulations. And setting measurable environmental goals and assigning responsibilities for meeting those goals have led to organizational changes that should sustain environmental improvement.

Keys to the success of the pilot have included:

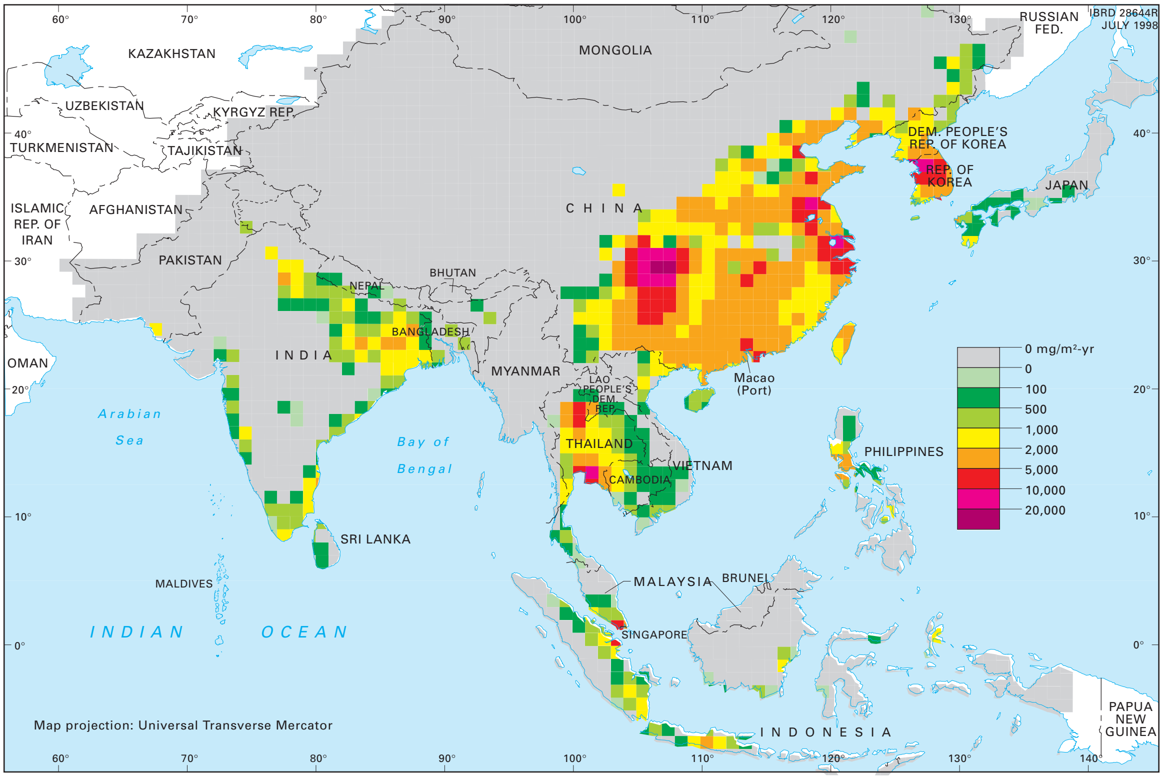
- Getting nudges from large clients and suppliers
- Combing expert knowledge and local technical assistance, and
- Using simple analytical tools to process available information and achieve scheduled milestones.

- Using *markets* to reduce environmental damage when appropriate, through such market-based regulatory instruments as pollution charges and tradable emission permits
- Determining appropriate roles for *central and local governments*—for example, administering regulatory instruments, monitoring, enforcing, and ensuring that basic environmental performance standards are maintained

Figure 7.5

Acid deposits above critical loads in Asia: The RAINS model

Computer models can now simulate the likely distribution of environmental damage.



Note: The figure shows, for 2020, expected sulfur depositions in excess of what ecosystems can safely tolerate. Source: Amann and Cofala 1995.

Box 7.6

Building on local knowledge to monitor and understand deforestation

Deforestation is a widespread phenomenon but one that is often only partly understood. New approaches build on local sources to provide small-scale, locally verified information on forest conversion and its causes. As exemplified by the International Forestry Resources and Institutions (IFRI) Research Program at Indiana University in the United States, started in 1992, such information can be collected through a network of collaborating research centers throughout the world. The centers agree on a common research method to support the collection of primary data on forest conditions, management, and uses. They then interpret and analyze for policy purposes the information gathered in the field. And they promote the formation and strengthening of local capacity for assessment.

This approach differs from such conventional ways of understanding deforestation as global monitoring, primarily based on national inventories and satellite imagery, and the use of research stations, providing information on the effects of human activities on forest ecology. The new program complements these methods by narrowing knowledge gaps on the physical, ecological, socioeconomic, and institutional characteristics of deforestation—and on the interplay of demographic, political, policy, and socioeconomic forces that cause deforestation.

An important policy message that the new approach suggests is that the different forms of collective action need to be integrated. Addressing the information challenges of deforestation, which is local in its determinants but national and global in its effects, requires mobilizing many actors. The players include local communities and national researchers for the collection and interpretation of field data, the international academic community for the establishment of common methods, and the donor community for the provision of resources.

- Involving *communities and civil society* in environmental management, with particular attention to publication of environmental information, the role of traditional knowledge, and appropriate informal regulation by local organizations, and
- Expanding the scope for *international cooperation,* with appropriate arrangements for monitoring, disseminating information, and encouraging compliance by sovereign states.

Using markets to achieve environmental goals

Given the efficiency of markets in processing information and allocating goods and services, market-based approaches to environmental protection seem well worth exploring. Taxes and tradable permits can correct spillover problems in many cases. For example, the trading program for sulfur dioxide emissions rights in the United States cut those emissions by almost 50 percent, at a significantly lower cost than alternative instruments (Box 7.7).

One of the few large-scale applications of market-based instruments in developing countries is China's pollution levy. Under this scheme, which covers several thousand factories, firms are subject to a levy for discharging pollutants beyond a predetermined level. The scheme has provided an incentive for factories to cut their emissions while maintaining the flexibility to adjust rates to local circumstances: concentrations of important water pollutants in the provinces subject to the levy dropped by about 50 percent from 1987 to 1993.

An interesting form of market-based pollution control envisaged under the Kyoto Protocol to the Framework Convention on Climate Change is joint implementation, or greenhouse gas emission offsets that are international in scope. This system promotes cost-effective control of greenhouse gas emissions by giving abatement credits to countries that sponsor abatement activities in other countries. This allows industrial countries with high-cost abatement options to satisfy their abatement commitments by identifying and exploiting lower-cost options elsewhere. It has been estimated that seeking interregional efficiency through such measures could reduce the costs of compliance to about a third of those under a system of fixed targets for each country.

Creating markets for environmental goods sometimes runs into problems, however. If markets are to function well, schemes must account for information imperfections and uncertainties about compliance costs and environmental impacts. Where information is limited, monitoring and other transactions costs can be substantial. This can happen if there are many point sources, for example, or if emission cuts are measured against a counterfactual baseline, as is done under joint implementation and in many U.S. energy efficiency programs. Market-based instruments can also require a radical shift in thinking. Environmental goods have traditionally been free, and many cultures treat environmental goods (such as water in some Islamic countries) as special and beyond price. In the United States, where market-based pollution control is most advanced, it took years to create the necessary markets. Even so, market-based approaches can be a cost-effective solution for many environmental problems.

Box 7.7

Creating markets: The U.S. sulfur dioxide permit trading program

Trade in sulfur dioxide allowances was introduced in the United States in 1995 through an amendment to the 1990 Clean Air Act. The U.S. Acid Rain Program is the first long-term, large-scale pollution control program to rely on tradable emission permits. In its first phase it is limited to 260 of the country's most-polluting power generation units. After its full implementation in 2000, the program will cover practically all fossil fuel–based power plants on the mainland.

The potential gains have not yet been fully exploited, but the volume of emission trades is picking up, and the initially volatile market price has stabilized. Sulfur dioxide emissions have dropped sharply to a level well below the allowed cap. And the costs of compliance have been lower than expected, even though monitoring and transactions costs are relatively high, at about $120,000 per smokestack.

Emissions trading was not the only reason why compliance costs have remained low. Reduced transport costs made low-sulfur coal from the Midwest more widely and cheaply available. Combined with technical innovations facilitating the blending of high- and low-sulfur coal, this greatly increased the scope for fuel switching, an abatement option that tends to be cheaper than the principal technical solution, namely, flue gas desulfurization.

The Acid Rain Program has been crucial in allowing utilities to process new information more quickly and to react flexibly to new developments. For many power companies, permit prices provide useful information about sectorwide abatement costs, prompting them to revise their abatement strategy. Other utilities have been surprised by the new developments, finding that they had overinvested in sulfur dioxide abatement. The trading system, however, allowed them to "bank" their excessive emissions cuts against future caps. With modern allowance and emissions tracking systems, transactions costs have started to fall, the market is becoming more fluid, and efficiency gains are increasingly being realized.

Some tentative conclusions may be drawn from the experience thus far. Tradable permit systems work, but they have to be designed carefully, and they may not be the optimal solution under all circumstances. They do allow actors to react more efficiently to changes in market conditions, but they do not prevent them from making mistakes.

Sometimes markets more generally fail because information problems aggravate environmental difficulties or prevent their solution. Such problems can prevent the efficient monitoring of compliance with environmental standards and limit the access of poor households to capital and insurance markets—with repercussions for the environment. For example, lack of access to commercial insurance causes poor rural households to keep larger herds than would otherwise be necessary, as insurance against losses, and that in turn accelerates land degradation. Lack of access to credit may also prevent poor households from installing environmentally friendly technologies with high startup costs, such as solar home systems.

Innovative institutional structures, such as energy service companies and leasing and hire-purchase agreements, can mitigate such problems. Energy service companies, because they generally have a financial track record, have the access to credit that individual households may lack. This makes it possible for them to procure renewable energy technology in bulk, install it in client households, and operate it for a fee. Customers pay only for the energy services, not the equipment. By spreading the costs to consumers over the life of the system, energy service companies also allow for a more affordable payment scheme, and thus reach a larger customer base. Leasing and hire-purchase schemes work in a similar way, except that ownership of the equipment transfers to the customer once the loan is paid off. Such schemes could bring affordable electricity to an estimated additional 50 million poor households worldwide.

Sharing responsibility between central and local governments

When technological, social, and institutional conditions permit, establishing markets is a powerful way to bridge the information gap between providers and users of environmental goods and services. But governments have important complementary roles in providing and managing environmentally relevant information (such as environmental indicators) and in ensuring compliance.

In the traditional approach to pollution regulation, the government collects information on both the social damage from polluting activities and the private cost of abatement. It then identifies an optimal emissions level, to be enforced by regulation. This may be difficult in complex situations with many polluters, but it could be viable when there are a few major polluters, so that the government can gather the relevant information at reasonable cost.

The scale of a policy issue—local, national, or global—usually dictates the level of government best equipped to tackle it. For natural resources, decentralizing management to state and municipal governments is likely to be a cost-efficient way of addressing local spillovers. It can improve the exchange of environment-related information in several ways:

- Local governments, closer to the stakeholders in environmental problems, are likely to incur lower costs in gathering information about the private costs of (and the social benefits from) mitigating activities.
- State and municipal governments can take advantage of their knowledge of local conditions to apply centrally determined guidelines on emission standards or land zoning restrictions. They can also promote the adaptation of framework policies established by national ministries.
- Decentralization can shorten the feedback loop between making decisions, observing the effects, and adjusting the initial decisions.

Decentralizing environmental management has risks, however. It requires considerable human and institutional capital: doing it without adequately trained personnel, institutional backstopping, and recurrent funding may be counterproductive. Nor is it enough to promote stakeholder participation. Like those of central governments, the incentives of local governments are affected by the electoral cycle—which may be too short to properly address long-term concerns, or too long for issues that require frequent interaction with stakeholders. Local communities may thus have to be encouraged to voice their environmental concerns. And even where decentralization is the appropriate course, central governments need to retain some key roles in managing environmental information across jurisdictions.

Involving communities and civil society

Environmental issues span geographic boundaries. And even in open societies, formal regulation relies on fixed rules (concentration standards, charge rates) that reflect the preferences of well-organized interest groups. In regions with great social and environmental diversity, reliance on the two conventional systems of resource allocation—markets and government regulation—may not provide the best approach to environmental management. Other forms of social organization may also need to contribute.

Social norms and environmental performance. In recent development research, attention has shifted from transactional arrangements (markets, regulatory instruments, and the like) to the social and institutional foundations of efficient transactions. Students of economic development are paying closer attention to social capital—to the relationships and informal institutions that support successful developing communities. Legal scholars are giving more attention to the strong complementarity between informal behavioral norms and formal rules in successful governance. Environmental researchers are identifying similar patterns in local regulation of environmental damage. Formal and informal regulatory mechanisms almost always coexist, with the latter often dominating in developing countries where the former are weak.

The recent literature on pollution control contains many accounts of how industrial plants respond to community pressure. In some instances plants reduce their emissions by installing new treatment facilities. In others they compensate the community indirectly by providing drinking water or new facilities, such as temples and community halls. In still others they refuse to address pollution, especially when the source is not clearly identifiable. Polluters will be more responsive if their environmental reputation has market value, or if enhanced perception of risk causes their asset values or credit ratings to be downgraded in financial markets.

Innovative environmental policies now stress the complementary roles of communities, markets, and governments in disseminating information on pollution abatement and creating incentives for it. Policymakers are learning that pressure groups can complement regulation. The public may know that a given industry discharges pollutants into the environment, but it rarely knows how much each factory is discharging. It is the second piece of information that, when disclosed, puts pressure on the firm and gives it an incentive to comply with pollution standards. Box 7.3 showed how Indonesia has enhanced self-regulation through a program for rating and disclosing the environmental performance of large polluters. Recent research on Argentina, Chile, Mexico, and the Philippines has shown that their capital markets reward good environmental performance (Box 7.8).

Recent experience in Ciudad Juárez, Mexico, also shows that information and community pressure can reduce pollution even by small, informal enterprises (Box 7.9). The common failure to regulate such enterprises has been attributed to high marginal abatement costs, the inability of firms employing mostly low-skilled labor to adapt nimbly, and the need to sell homogeneous products in highly competitive markets. But Ciudad Juárez suggests that inappropriate institutional and informational arrangements deserve more of the blame.

In some cases the transition to sustainable environmental management may depend not so much on the availability of knowledge about appropriate technology, but on the right way of disseminating it. Community mechanisms, based on communication among different social strata and age groups, can provide innovative solutions (Box 7.10).

Local ecological information. In rural areas especially, local communities are both the source of key environmental information and the custodians of traditional environmental know-how. Local residents, the primary conduit for fundamental data on forest ecology and use, are thus a basic link in network-based approaches to the study and analysis of deforestation (see Box 7.6). In the effort to protect biodiversity, taxonomic information is important for establishing priorities, determining baselines against which to measure the effectiveness of conservation efforts, and guiding screening and other activities to identify genetic traits of indigenous species that may be of use in developing new drugs or improved plant varieties.

Box 7.8

Information and pollution control incentives from capital markets

In the traditional regulatory model, profit-maximizing firms control pollution to the point where the rising marginal cost of abatement balances the expected incremental penalty for noncompliance. Yet polluters often control emissions even when expected regulatory penalties are very low. Regulation is clearly not the only incentive for pollution control, and recent research points to capital markets as having unrecognized potential here. They create incentives for pollution control when they revise their judgments about firms' value in response to favorable or unfavorable information about their environmental performance.

The impact of firm-specific environmental news on market value works through various channels. Reports of high levels of emissions by a firm can signal to investors the inefficiency of its production processes. They can also invite stricter scrutiny by regulators, environmental groups, and the polluter's neighbors. And they can result in a loss of reputation among environmentally conscious consumers. All these changes may impose costs on the firm and lower its expected stream of profits and thus its share price. In the same way, announcing good environmental performance or investments in cleaner technologies can enhance expected profits.

Recently a World Bank team studied the reaction of stock markets in Argentina, Chile, Mexico, and the Philippines to news about environmental performance. None of the four countries has a strong record of enforcing environmental regulations. Yet a firm's share price was found to rise by an average of 20 percent when its good environmental performance was publicly recognized by the authorities, and to fall from 4 to 15 percent in response to publicized citizens' complaints about pollution.

These results suggest that global capital markets are using information about environmental performance, and that financial decisions are an important missing link in explaining polluters' behavior. Public provision of reliable information about environmental performance can thus influence polluters indirectly, through financial markets, even when it is difficult to confront them directly, through formal regulation.

Box 7.9

Information, community pressure, and adoption of clean technology in Ciudad Juárez, Mexico

From an environmental perspective, there are good reasons to assume the worst about small plants in pollution-intensive industries. Many unlicensed microenterprises operate with unskilled labor in highly competitive markets, so it seems likely that they would be either unwilling or unable to control pollution effectively. Take Mexico's 20,000 small, traditional brick kilns. Fired with highly polluting cheap fuels, such as used tires, garbage, used motor oil, and wood scrap, these kilns are a leading source of air pollution in many cities, and an especially serious health hazard to those who happen to live near brickmaking *colonias.* But regulating them by conventional means would appear impossible.

Traditional brickmaking typifies labor-intensive, low-technology production in the urban informal sector. The four main tasks—mixing earth and clay, molding the mixture into bricks, drying the bricks in the sun, and firing them in a primitive adobe kiln—are all performed by hand. The average kiln employs six workers and generates about $100 a month in profits. Most brickmakers live next to their kilns in rudimentary houses with no sewers or running water. The average kiln owner has three years of schooling, and about a quarter are illiterate.

In the early 1990s a coalition led by a private association, Federación Mexicana de Asociaciones Privadas (FEMAP), began introducing clean-burning propane into the brickmaking *colonias* of Ciudad Juárez. This amounted to significant technological change, not just simple fuel switching, because it involved substantial fixed costs: transactions costs, learning costs, costs of procuring propane burners, and costs to modify the kilns to withstand higher temperatures. Other obstacles included the brickmakers' financing constraints, their lack of appreciation of the health damage caused by burning debris, the economic attraction of cheap but dirty fuels, and a virtual absence of formal regulatory pressure. Nevertheless, by late 1993 between 40 and 70 percent of the 300 or so brickmakers in Ciudad Juárez had adopted propane as their primary fuel.

How did FEMAP defy the conventional wisdom? A research team at Resources for the Future, a U.S.-based, nonprofit environmental organization, identified three keys to its success. First, it provided appropriate information: local universities set up training programs for kiln operators and educated them and the surrounding communities about the health threat. Second, the propane company encouraged kiln operators to switch by providing free access to all the needed combustion equipment except the burner itself. Third, project organizers worked with leaders of local trade and community organizations to pressure brickmakers to adopt propane.

Ciudad Juárez's experience shows both the promise and the limits of informal regulation. In the early 1990s, with propane only about half again as costly as debris, the FEMAP initiative induced widespread adoption of a cleaner technology by informal sector polluters. But the recent elimination of fuel subsidies by the Mexican government has dramatically increased the price of propane relative to debris. Faced with this additional change in incentives, most of the kiln operators reverted to traditional fuels. Powerful though it may be, informal regulation has not repealed the laws of economics.

Costa Rica is experimenting with the direct involvement of local people in developing its biodiversity inventory of the country's wild lands. By combining local traditional knowledge with basic formal training in taxonomy, Costa Rica's INBio (Instituto Nacional de Biodiversidad) is developing a new profession, that of the parataxonomist, responsible for the basic field work for the inventory. Not merely a collector, the parataxonomist is also the initial cataloguer of specimens and a more immediate link to the communities in and around Costa Rica's wild lands.

Sustainable agriculture. In many parts of the developing world, new market opportunities offered by global economic integration, often coupled with subsidization of inputs, give incentives to commercial farmers to pursue short-term increases in yields through the use of agrochemicals or wasteful use of water. Meanwhile, credit-constrained subsistence farmers, often displaced from more fertile areas toward the agricultural frontier, are forced to convert wilderness areas to cultivation and cannot invest in soil-conserving techniques. In both cases the appropriate generation, dissemination, and use of knowledge on sustainable farming practices are essential. Knowledge-intensive agriculture has important direct and indirect roles in conserving natural resources. Sustainable intensification of agriculture through biotechnology and integrated pest and nutrient management contributes to the conservation of resources in existing cultivated areas. It also helps reduce pressure to convert forests and other wild habitats to new production.

Governments in many developing countries are considering complementary approaches to traditional public extension schemes, to encourage technological progress in rural areas. Communities may have important skills for adapting general principles of agricultural sustainability to local conditions, and they are often effective transmitters of knowledge. A small group of trained farmers may inspire more trust than outside extension officials and thus have a better chance to promote innovations. They also provide efficient feedback to professional extensionists on the successes and failures of new technologies (see Box 7.4).

Ecolabeling. Consumers in high-income economies tend to be relatively sensitive to the environmental pedigree of the goods and services they buy, whether produced domestically or imported. If consumers can be provided with credible information on the "greenness" of their purchases, the powerful market incentives that result can induce producers to switch to environmentally friendly products and processes. For this to work, however, it is not enough for a given market to be environment-friendly. Mechanisms are needed to convey information about the actual practices that producers are following.

Consumers may be less interested in the certification of products with environmental impacts far back in the production chain. But for products with more discernible health benefits, such as organically farmed vegetables, new, ecolabeling-based markets seem more promising. In Canada food retailers and organic producers alike believe that a solid niche market of 10 to 15 percent could exist for organic products by 2000.

Developing countries seeking to tap new markets created by ecolabeling must meet three main requirements. First, internationally recognized standards of certification have to be established and promoted. For this international NGOs have to help in mobilizing the needed technical, financial, and consensus-oriented political resources. Second, a network of private independent certifiers needs to be encouraged at the country level, and the potential for governments to monitor compliance with internationally recognized standards needs to be explored. Third, national and local NGOs—in partnership with the private sector, and supported as necessary by funding from foundations or development agencies—have to disseminate information about "green" market opportunities and knowledge of sustainable production technologies to developing-country producers.

International cooperation

Solving environmental problems that reach across national boundaries requires international cooperation. The most successful approach thus far to limiting acid deposition in Europe has been through a European Acid Rain agreement. Similarly, the Vienna Convention and its associated protocols have been essential in protecting the ozone layer.

Collaboration on transboundary problems (discussed more fully in Chapter 9) is in many respects more difficult than dealing with local ones. Objective information about compliance with international agreements can be hard to come by, as the costs of global monitoring are often high, and many international treaties rely on a system of self-monitoring whereby each signatory reports on compliance in its own territory. More important, institutional mechanisms to compel sovereign states to comply with environmental regulation generally do not exist internationally. Although in some instances countries agree to act for the common good, successful international environmental agreements generally have to be in the self-interest of all participating parties.

Economic theory casts some doubt on the feasibility of such arrangements. Even when collaboration is beneficial

Box 7.10

Disseminating knowledge on sustainable irrigation in Brazil

In many countries the irrigation sector is the largest water user, accounting for up to 80 percent of consumption. It is also a wasteful user, because of poorly maintained infrastructure, inefficient technology, and negligent management. Low-value crops are often grown with expensive irrigation water that could be put to better use on higher-value crops or outside agriculture altogether. In addition to the high cost to governments of subsidizing irrigation systems, widespread irrigation contributes to drainage and salinization problems and groundwater pollution, and thus to the abandonment of formerly fertile land.

Often the problem is that knowledge about appropriate technology is likewise inefficiently distributed. A counterexample comes from a World Bank project in the Formosa irrigation district in Brazil's northeastern state of Bahia. When the project started, farmers in the local water user association were reluctant to adopt efficient water management options, such as water-saving sprinkler systems and higher-value crops. Water charges did not cover operation and maintenance costs, and the system was unsustainable.

In 1995 an analysis of the reasons for the limited interest in change led to an emphasis on involving the farmers' children, and thus to Projeto Amanhã (Project Tomorrow). A vocational school was founded to teach the younger generation about better irrigation, new agricultural techniques, and plant nursery management. With 120 students per class, the school has expanded to offer classes on sewing, furniture building, and beef and poultry production. Students also learn how to run sawmills and repair tractors. The school has 100 hectares of land planted with high-value crops for educational purposes. With the revenues from all these activities, it is self-sufficient.

The school has turned the project around. The water user association, which administers Projeto Amanhã, now has both older and younger members and is recovering between 80 and 100 percent of the irrigation district's operation and maintenance costs. The young people have convinced their parents to try new technologies and to plant high-value crops. One 1996 graduate reported that, before the project, his mother and eight siblings had barely survived by planting beans on their 15-hectare plot. Now he has started to grow high-value mangoes, bananas, and passionfruit, in the process increasing his family's net annual income 30-fold, from about $400 to $12,000.

to all countries, it is usually even more attractive for countries to free-ride on agreements undertaken by others. Moreover, there is some evidence that international cooperation may be most likely where it is least needed—where unilateral action by countries would have gone a long way toward solving the problem anyway. The high transactions costs of multiparty negotiations are another impediment.

With modern monitoring and communications tools reducing transactions costs, and with international trade strengthening the economic links between countries, the number of regional and international environmental agreements has been growing in recent years. Cooperative efforts are under way to protect the Red Sea, the Aral Sea, and Lake Victoria. True, not all international environmental agreements have been successful. But several examples—such as the Vienna Convention—suggest it is not impossible to overcome the incentives for countries to free-ride. The challenge is to design—through side payments, fostering of global markets, or other incentives—agreements in which participation and continuing compliance are in the interest of all parties.

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This chapter has identified two main issues in the relationships linking knowledge, information, and environmental management. The first concerns the role of knowledge and information in identifying environmental problems and solutions. Environmental degradation is the result of a complex pattern of market, policy, and information failures. And although policymakers, industries, and the public are growing more aware of the seriousness of environmental problems, better understanding their causes, and identifying solutions, important knowledge gaps and information barriers remain.

To get environmental concerns into the mainstream of development efforts, the coherent and systematic measurement of environmental quality and its integration with indicators of social welfare are essential. Good progress has been made in the construction and use of environmental indicators and in devising greener national accounting aggregates. But attempts to measure sustainable development—with indicators that tightly link economic and environmental phenomena—are still in their infancy. And more work is needed to show how (and how much) a better quantitative understanding of sustainable development can affect economic policy.

Use of these environmental indicators must proceed down from the macro level to sectors and projects. At the sectoral level this means more strategic environmental assessments: comprehensive analyses of the environmental implications of policies, strategies, and programs for a given sector or geographic area (such as an urban area, coastal zone, or watershed). At the project level a broad toolkit of instruments is needed to ensure that investment projects are environmentally sound.

The second issue concerns institutions: what forms of social organization are best suited to deal with different environmental problems? Promising new approaches to informationally efficient environmental management are starting to emerge, supported by the information revolution, which increases transparency, allows the involvement of broader groups of better-informed stakeholders, and generally reduces the transactions costs of monitoring and trading environmental commodities. At the core of today's environmental agenda is identifying creative ways of combining markets, governments, and civil societies to promote efficient mechanisms for the generation, diffusion, and use of sound environmental knowledge.