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SPECIAL REPORT

ENVIRONMENTAL PROBLEMS IN CHINA: ESTIMATES OF ECONOMIC COSTS

VACLAV SMIL

How sustainable is a country's economic growth when the costs of accompanying environmental damage are factored in? For China, faced with some of the worst pollution and environmental degradation in the world, the question is especially urgent. A first step is to evaluate the hidden costs of its extraordinarily rapid economic growth.

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SUMMARY

Today's China experiences every imaginable environmental problem, yet its capacity to deal with these challenges is limited. China's poor oil and gas resources mean that its industries and services still overwhelmingly rely on coal, an inefficient fuel and a major polluter. Moreover, it has extensive areas of badly damaged ecosystems. And, like other countries in the early stages of rapid industrial development, China has been slow to allocate capital for environmental management. These factors, together with China's huge population and ambitious development aspirations, make it the world's most worrisome case of environmental degradation, with global repercussions.

The annual cost of China's environmental pollution and degradation is probably at least 10 percent of its gross domestic product (GDP) and may well be as high as 15 percent. But China has been spending far less on environmental protection and management than even the 1.5 percent of GDP recommended by the country's leading environmental experts.

The effects of pollution and environmental degradation are everywhere. Chronic lung diseases aggravated by air pollution accounted for approximately 25 percent of all deaths in the late 1980s. In only 6 of China's 27 largest cities is drinking water quality within state standards. Contamination of crops by polluted water endangers health and reduces opportunities for export of products. And the loss of arable land to urban encroachment and soil erosion means that, by the year 2000, Bangladesh and Egypt will be the only two populous nations with less arable land per capita than China.

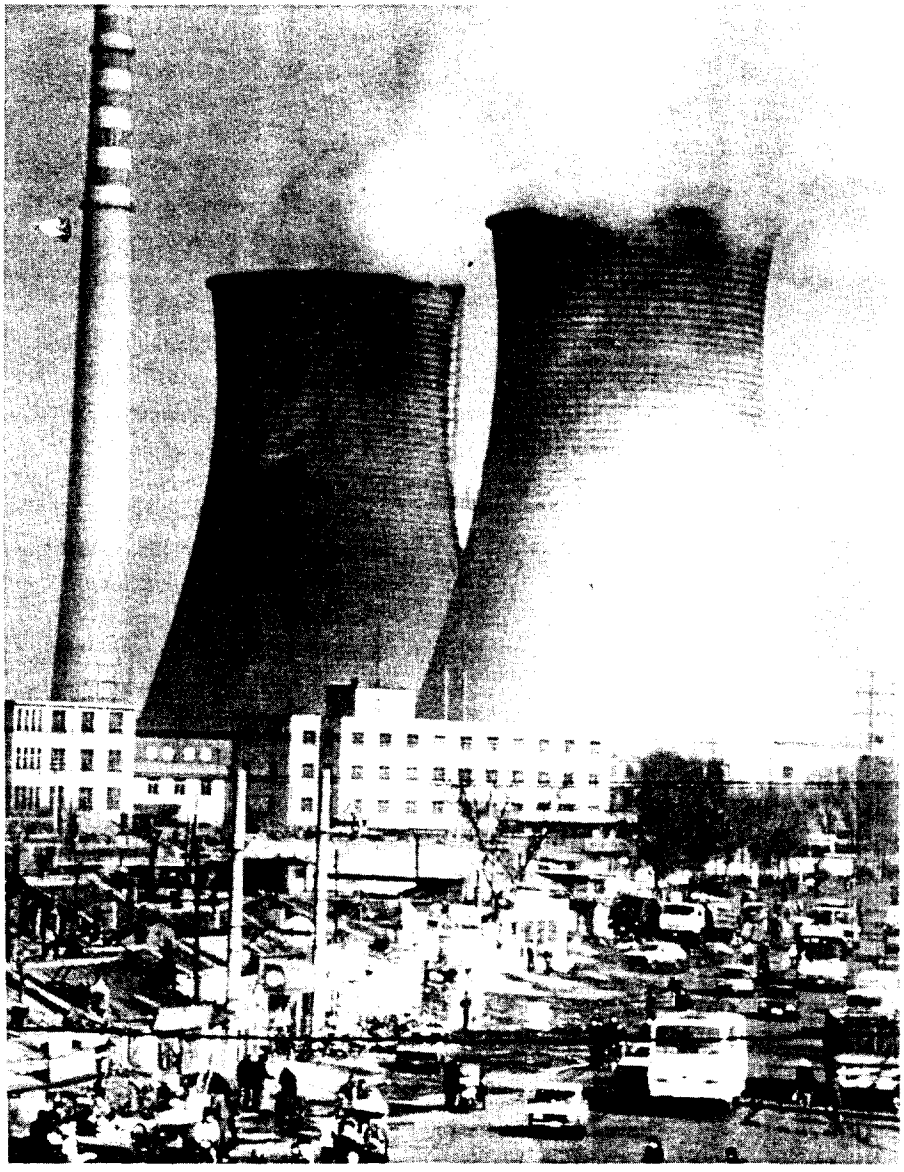
If China were to consume resources at the level of South Korea or Taiwan and import crude oil and grain at rates comparable to those of other rapidly growing East Asian economies, it would need more energy and more cereals than are currently available on the world market. Securing the largest possible share of its energy and food needs from domestic sources will be important not only for China's economic progress but also for global stability. Such a strategy can succeed, however, only when China uses its resources efficiently and makes protection of the environment, and a gradual shift to more sustainable ways of running its economy, a matter of high priority.

Do all that you know, and try all that you don't...

Lewis Carroll
The Hunting of the Snark (1875)

My curiosity was piqued in 1989 by news of a study by the Chinese Academy of Social Sciences that put the annual cost of China's environmental pollution and degradation at about 8.5 percent of its gross national product (GNP). This was a higher share than the few estimates available for Western nations, but, given China's serious environmental problems, I suspected that the actual total might be even higher. When repeated attempts failed to uncover the analytic details from which this estimate was derived, I decided to make some basic estimates myself.

My first rudimentary attempt appeared in a paper on environmental change as a source of conflict and economic losses in China.[1] That preliminary work made me more



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Populations in every major northern city and many urban areas in the south are exposed to air pollution levels that are three to seven times higher than World Health Organization guidelines. (Shown: A coal-burning plant in Shenyang, China.)

Without a more realistic valuation of natural resources we will not be able to slow the rate, and eventually reverse the process, of worldwide environmental degradation

interested in taking a closer look at the possibilities and pitfalls of such accounting exercises. After completing *Global Ecology*,[2] I considered writing an extended critique of environmental valuations but then decided to make the exercise as practical as possible and to prepare estimates of the economic cost of environmental pollution and degradation in China.

In undertaking this study, I had at least three objectives: (1) to provide a basic introduction to the advantages and limitations of environmental valuation; (2) to offer a concise but comprehensive database; and (3) to provide a foundation for further studies. The explanations of all assumptions and calculations may be somewhat tedious, but their inclusion will facilitate replication and critiques of the study and thus improve subsequent attempts at more accurate valuation.

The exercise could also have practical value for those interested in environmental valuation in general, and in China's environment in particular, and could provide arguments for basic policy discussions. The approximations of the relative costs of all major environmental problems may be helpful for pointing further studies toward the most effective management choices or focusing attention on the most useful benefit/cost ratios.

VALUING THE ENVIRONMENT

Concerns about the environment have always carried at least an implicit message of needed change. A generation ago, when these concerns gained widespread public attention for the first time, the required changes seemed to be more a matter of selective controls and better management than of profound economic restructuring. A deeper appreciation of the links between the economy and the environment has changed that perception.

By the late 1980s it became clear that, to cope effectively with the many environmental effects of global population and economic growth, we needed to develop a new economics that is consistent with the long-term maintenance of biospheric integrity. Meeting this challenge will require, among other things, better ways of assessing the value of environmental goods and services. Without a more realistic valuation of natural resources we will not be able to slow the rate, and eventually reverse the process, of worldwide environmental degradation.

I am well aware of the many arguments against trying to value environmental goods and services. I recognize that what we can do today is still very fragmentary and that for many types of environmental problems there may be no generally acceptable solutions even in the distant future. In the spirit of the quotation from the work of Lewis Carroll, which serves as this work's epigraph, however, we should try: environmental valuation can be useful for basic policy assessments and is sometimes persuasively practical. At the very least, attempts at environmental valuation improve the quality of the questions asked.

CHINA'S CASE

The decision to focus on China is more than a matter of my long personal involvement in Chinese affairs. As an ecologist interested in the interaction of environment, energy, food,

population, economics, and public policy, I can think of no better national example for assessing the value of environmental change.

The most effective advances in managing global environmental change can come from improvements in a small number of the largest contributors to the earth's degradation. These largest "contributors" include countries, such as the United States and Canada, whose affluence, combined with widespread underpricing of resources, makes them the world's most prodigious users of energy and the largest per capita producers of waste. On the other extreme are large, poor countries, where the combination of huge populations and enormous developmental aspirations produce high rates of environmental degradation.

China dominates the latter group. Its population, which has surpassed 1.2 billion, is increasing by nearly 15 million persons per year. Achieving China's goal of quadrupling its 1980 per capita gross domestic product (GDP) by the year 2000 has required extraordinarily rapid economic growth. When valued in terms of purchasing power, rather than artificial exchange rates, China is already the world's third largest economy (behind the United States and Japan), and its growth record during the 1980s and the early 1990s indicates that it will move to the second place very soon.

These rapid economic advances have, however, been based on restricted resource availability and a relatively weak environmental foundation. China's poor hydrocarbon resources mean that its industries and services are still overwhelmingly coal-based and hence inherently less efficient in converting primary energy into economic products. Like other countries in similar stages of economic development, China also has shortages of capital for environmental management. Unlike many other nations, however, it already has extensive areas of badly damaged ecosystems, some with long histories and others the result of misguided post-1949 policies. This adds up to the world's most worrisome case of environmental degradation, with obvious global repercussions.

Deforestation, desertification, and soil erosion have marked millennia of Chinese history and have intensified since the establishment of the People's Republic. The Communist leadership launched a series of environmentally destructive campaigns—most notably the Great Leap Forward, with its massive tree cutting and neglect of agriculture, and the subsequent simple-minded Maoist promotion of grain cultivation, with its destruction of grasslands and wetlands—that weakened the nation's very biophysical foundations. China's peculiar industrialization history—from Stalinist five-year plans to Maoist delusions of small-scale self-sufficiency to rapid integration into the global market—has also generated voluminous streams of wastes and caused severe air pollution from the massive combustion of raw coal and extensive water contamination from huge state plants and from millions of new small enterprises.

Today's China therefore experiences every imaginable environmental problem, yet its capacities to deal with these challenges are limited. A comprehensive and satisfactorily accurate quantification of the costs of environmental change is beyond anyone's analytical reach. There is, however, enough direct and indirect information available to prepare ranges of estimates that will be useful for at least an initial appreciation of the burdens environmental degradation imposes on the country's economy.

ECONOMIC COSTS OF ENVIRONMENTAL CHANGE

Global economic expansion has put a great burden on the earth's resources. Their exploitation and conversion have led to environmental degradation of such unprecedented speed and magnitude that the long-term sustainability of civilization must be questioned.[3] A great deal of perceptive and innovative writing has been published on this theme since the mid-1980s,[4] but, in essence, only one fact must be understood, accepted, and acted upon: all economies are nothing but subsystems (albeit very complex ones) of the global ecosystem. They cannot continue to prosper unless the system in which they are embedded maintains its fundamental structures and intricate dynamics. That is, there can be no viable economies without a steady inflow of natural goods and a constant reliance on a huge array of irreplaceable environmental services.

Demand for Environmental Goods and Services

Throughout history, all complex cultures have been preoccupied with securing mineral resources. Efforts to ascertain the location and quantity of a widening array of ores and fuels and activities to extract them and convert them into commercial products have been core endeavors of both traditional and modern economies. Increased production has been accompanied by concerns about resource depletion.

When we destroy ecosystemic structures in a quest for mass flows of inexpensive natural goods we also destroy a set of environmental services whose ultimate value is invariably higher than the ephemeral gain from the exploited stock—and whose combined benefits cannot be effectively replicated by any human action

In retrospect, however, it turns out that these concerns are misplaced: there have been no instances of running out of a major mineral resource on a large scale. Instead, long before reaching the point of depletion, the rising cost of harnessing a diminishing resource pushes us to do one of three things, singly or in combination. First is to lower demand by devising better product or convertor designs and smarter utilization patterns; the lowered specific consumption greatly extends the lifetime of known stocks. This trend has been seen with every mineral resource: after first rising and then reaching a clear plateau, the specific consumption of all metals and fuels (measured in terms of mass or energy value per unit of GDP) has declined as countries proceed through the successive stages of economic development.[5] A second option is to turn to lower-quality deposits that are either easier to obtain or, with improved techniques, cheaper to recover per unit of final useful product than the originally exploited stocks; this shift has occurred repeatedly in the mining of metals and fuels. Third is to find effective substitutions. Substitution of silicon for copper in telecommunications is perhaps the best example: the former element is the second most abundant constituent of the earth's crust.

Innovation and substitution can also greatly extend the availability of renewable resources. Harvesting an entire tree and chopping it up to make engineered lumber (ranging from particle boards to beams) uses virtually all of the tree, in contrast to the traditional use of only the tree trunk, which converts less than half of the woody biomass into a commercial product. The new technique has an added structural advantage as well: engineered products make better building materials than cut wood. Other examples of successful substitutes include replacing traditional ridge-and-furrow irrigation with a central pivot sprinkler that can easily double field-irrigation efficiency and introducing a crop with inherently lower water demand (e.g., sorghum instead of wheat) to lower water consumption.

The situation is quite different, however, with environmental services that bind the web of life and sustain its evolution: no organism can do without them and in only a few exceptional cases can they be replaced through technical fixes. When we destroy ecosystemic structures in a quest for mass flows of inexpensive natural goods we also destroy a set of environmental services whose ultimate value is invariably higher than the ephemeral gain from the exploited stock—and whose combined benefits cannot be effectively replicated by any human action.

These services range from the obvious to the obscure, but no ranking by importance makes sense: the interconnectedness of biospheric cycles and flows makes such an exercise futile. For example, a mature temperate forest harbors considerable biodiversity: its roots and thick litter layer virtually eliminate soil erosion; its biomass and protected soils store precipitation, moderate runoffs, and influence local climate; and its plants act as sinks for carbon dioxide (CO_2) and other atmospheric compounds. Dryland fields cannot maintain their long-term productivity unless the organic matter in their soils can support tons of bacteria and fungi and hundreds of kilograms of nematodes and earthworms in every hectare. The paddies of tropical Asia would lose a

large share of their productivity without the ubiquitous nitrogen-fixing bacteria that produce an essential macronutrient for the staple crop.

These realities present new accounting challenges. Calculating the value of timber as a commercial commodity is fairly simple, but valuing the forest from which it was taken is less clear-cut. The lost water-storage capacity can be regained by building a reservoir, but are the costs of dam construction a reasonable surrogate for the value of the lost service? Such replications may suffice in gross quantitative terms, but are they an adequate substitute for the unique environmental services provided by complex ecosystems? A reservoir built to replace the water-storage capacity of a large forest can silt up rapidly. Even if it remains silt-free, its water quality will almost certainly be worse than that of waters that have undergone filtering and bacterial processing in the forest, the equivalent of expensive tertiary water treatment. Similarly, synthetic compounds can be substituted for nitrogen provided by symbiotic bacteria in a paddy field, but these fertilizers will neither supply the organic matter to maintain soil structure and the phytomass carbon to feed invertebrates and fish living in the water, nor absorb carbon dioxide and release oxygen. Moreover, without the bacteria whose enzyme-driven reductions release nitrogen from the soil, the atmosphere's immense nitrogen stores will become rapidly exhausted.

Estimating the worth of ecosystemic services that are vital to human welfare is therefore an enormous analytical challenge. The value of environmental services is, in both evolutionary terms and on the timescales of civilizations, clearly higher than the value of the goods obtained by destroying or severely compromising the biospheric interconnections. Our estimates and calculations of these benefits may never capture their real worth, but doing our best has clear rewards: it launches us toward a goal that may never be reached but on a journey that is essential for improving the odds of our long-term survival.

Setting Up New Economic Accounts

The new economics needed to responsibly evaluate the real costs of rapid growth will require the establishment of a new set of national accounts that go beyond the traditional valuation, assess cumulative changes in natural assets, and extend input-output charts to environmental services. This approach will eliminate two fundamental weaknesses of existing national accounts: (1) their virtually complete neglect of environmental deterioration, and (2) their treatment of depletable natural assets as current income contributing to the rise of GDP totals.

Existing practices, which confuse the depletion of environmental assets with the generation of income, lead almost inevitably to the conclusion that high rates of economic growth can be achieved by the rapid exploitation of natural resources. Modern economies have followed this precept in countless cases, boosting income in the short run but ultimately losing great natural wealth.

When mineral resources are involved, undervaluing the environmental costs of extraction may bring a great deal of local or national discomfort (e.g., the demise of mining towns, sudden shocks to single-commodity economies after major price swings) but have few long-term consequences: the region's habitability, agricultural productivity, and sustainable economic fortunes may actually increase. The consequences are much more worrisome, however, when such action involves environmental resources that, once destroyed, cannot be renewed for perhaps thousands of years, or at least for many generations, and whose degradation or loss compromise the maintenance of basic environmental services. An example is the rapid and massive cutting of tropical forests. The short-lived generation of higher income is followed by an avalanche of environmental degradation. This process includes soil degradation (loss of nutrients, lowered water storage capacity) and sharply increased erosion rates that cause higher downstream silting, higher runoffs, changed evapotransipration,* and surface albedo,† all leading, if the area is large enough, to discernible changes in climate.

The economic cost of these environmental ills is difficult to calculate, as the degradative processes can continue for many decades, with sometimes delayed and unforeseen consequences. A standard accounting approach may therefore chart continuous growth, whereas a national accounting approach that tries to incorporate this long-term, if not permanent, loss of environmental wealth may show stagnation and even decline.

A revealing example of this approach is H. Daly and J. B. Cobb's index of sustainable welfare calculated for the U.S. economy.[6] By this

*The process of transferring moisture from the earth to the atmosphere by evaporation of water and transpiration of plants.

†The ratio of light reflected by the earth's surfaces to that received by it.

Freeing of many commodity prices has driven Chinese energy prices up, but they still almost completely ignore the cost of environmental pollution and degradation

measure—which includes the costs of commuting; car accidents; urbanization; water, air, and noise pollution; loss of farmlands and wetlands; and depletion of nonrenewable resources as well as an estimate of long-term environmental damages—the U.S. economy stopped growing after the late 1960s and has been declining since the mid-1970s. During the 10 years between 1976 and 1986, U.S. per capita GNP rose by about 20 percent, but the per capita index of sustainable welfare fell by about 10 percent. If basically correct, this analysis reveals that the economic growth of the last generation has been nothing but an accounting artifact.

A less dramatic result came from a World Resources Institute study that found that more than a quarter of Costa Rica's pre-1989 economic growth disappeared once adjustments were made for the depreciation of forests, soils, and fish stocks.[7] The real decline should in fact be much higher, as the new account did not include the value of lost forests as natural habitats, water storage systems, and tourist attractions.

A detailed methodology for "integrated environmental and economic accounting" was published by the United Nations,[8] but the inherent difficulties of this approach mean that such valuations will not replace standard GDP assessments anytime soon. Indeed, even their relatively common use as companions to established accounting methods will take many years, if not decades. Perhaps the best way to approach this challenge is to agree that if new calculations reflecting environmental concerns are to become effective and eventually widely accepted they cannot aim for the complete inclusion and valuation of environmental assets.[9] Such a goal may be unattainable even in the very long run. Still, a partial and gradual approach—beginning with variables that are more readily quantifiable—is highly desirable.

During the coming decades a gradual expansion of these new economic accounts will be an enormous challenge, even for the richest industrialized countries. Nonetheless, the Chinese are now officially committed to this task: a report on China's participation in the Rio Conference on Environment and Development calls for protecting China's environment by a number of economic means and explicitly mentions the eventual goal of including natural resources and the environment in the accounting system of the national economy so that market prices will better reflect the environmental cost of economic activities.[10] Although this is clearly a desirable goal, it is difficult to foresee how Chinese accounts could achieve either the depth or the accuracy of new German, Dutch, or U.S. national accounts during this decade. A better appreciation of pollution and degradation processes is only one part of this challenge: Chinese statistical reporting must also be improved. Its quality is illustrated by the fact that, in 1994, the first nationwide survey of statistical reporting uncovered 60,000 cases of false statistics in just three months, prompting the government to threaten widespread punishment.[11] Even when basic data reliability can be ensured, years of collaborative work will be needed to structure and improve these new accounts.

A shift in economic valuations will also require a transition to more realistic prices for energy, materials, water, and food. This shift could be speeded up by an assessment of the magnitude of existing economic

losses caused by the environmental pollution and degradation that accompany the production and consumption of these vital commodities. It is here that an individual researcher can make a useful, if initially only largely heuristic, contribution, i.e., by constructing a practical framework to assess such costs on a regional or national basis and providing order-of-magnitude cost estimates with aggregates that can be used to demonstrate the relative burden of environmental change.

Paying Real Prices

The transition to paying real prices—or at least prices that better reflect the costs of environmental degradation—will necessarily be a long one. This gradual process can, however, be expanded and accelerated by extending realistic assessments of value to a wider range of commodities and services and by constructing more inclusive accounts.

Perhaps the greatest progress in this direction has already been achieved in internalizing costs of a number of environmental burdens related to the production and conversion of energy—that is, to include the cost of environmental damage in the price of the final product. No country has truly realistic energy prices, but most Western economies have made notable progress toward more rational energy pricing.

In contrast, virtually all Chinese energy prices were extraordinarily unrealistic until the mid-1980s. Because of the state-dictated give-away price of raw coal, even the best coal mines working some of the world's richest seams of bituminous coal yielded no profits. Freeing of many commodity prices has driven Chinese energy prices up, but, as the following examples show, they still almost completely ignore the cost of environmental pollution and degradation.

The first example centers on regulatory action. Two generations ago, underground coal miners in the West were commonly exposed to excessively high levels of coal dust and lacked any contractual protection for early retirement or premature death caused by black-lung disease. Today's regulations, however, limit the amount of dust in mines, and union contracts contain disability and compensation provisions. Where properly enforced, these measures have successfully internalized one of the most immediately destructive personal effects of energy production. The Chinese, on the other hand, have yet to replicate this achievement, which, given the size of the country's coal industry, would prolong literally million of lives. The current situation is shocking, with chronic bronchitis and pneumoconiosis incapacitating men in their thirties. Miners working in Hunan's Zexing Mine Bureau collieries are forced to stop working at just 36 years of age, after fewer than 12 years of service.[12]

A second example concerns pollution control devices. A technical fix with a great deal of public impact has been the nearly universal installation of efficient electrostatic precipitators that remove all but a tiny fraction of particulate matter* from the flue gases of coal-fired electricity-generating stations and industrial boilers. These devices have sharply lowered particulate concentrations in every industrialized country, and the Chinese have been installing them on all new large power plants and retrofitting them to many older and smaller generating units.

Despite these advances, however, Chinese particulate pollution remains very high, the result of uncontrolled emissions from millions of household stoves and thousands of small industrial boilers. Particulate emissions from stoves can be lowered economically only by a combination of more efficient designs and better fuels. Industrial boilers, on the other hand, can be equipped with readily available, but often relatively expensive, control devices (although not necessarily with electrostatic precipitators).

Numerous coal-fired electricity-generating stations in the United States and in Europe are also equipped with flue-gas desulfurization units that remove 60 to 90 percent of all generated sulfur dioxide.[13] This process reduces the atmospheric concentration of sulfates, which are inarguably implicated in reducing visibility, speeding the corrosion of some metals and the deterioration of paints, and increasing the acidity of rain. As yet, China has no desulfurization units on coal-fired stations, but their installation may be necessary in parts of southern China where acid deposition is already causing serious damage to forests. Given the expense of this undertaking, however—desulfurization increases both capital and operating costs by at least 20 percent—initial installations will likely require foreign aid. The Japanese are already interested in providing aid: they have experience with desulfurization and are living downwind from what is already one of the world's largest concentrations of coal-fired power plants.

Similar reviews can be done for water (which is greatly underpriced everywhere), food (a matter of

*Particulates are solid or liquid particles suspended in the air that cause or worsen respiratory illnesses.

extreme political sensitivity in China with its enormous state subsidies for urban consumers), and wood (unsustainably harvested in every major logging area). Obviously, resistance to paying real prices will be high, and there will be many disputes about appropriate ways of assessing the costs of pollution, resource depletion, and environmental degradation.

Most disagreement will arise, as in the recent past, from three interlinked causes: (1) problematic accounting approaches (ranging from good ones using weak data to dubious ones based on poor scientific understanding), (2) difficulties inherent in monetizing degraded or lost environmental services (what surrogates can be used for essentially irreplaceable functions?), and (3) no less challenging difficulties in quantifying the costs of human suffering and premature death.

There is no shortage of approaches to quantifying the costs of environmental degradation

MONETIZING THE COSTS

There is no shortage of approaches to quantifying the costs of environmental degradation.[14] Some are derived from readily available market values, some are based on people's willingness to pay (so-called contingent valuations), and others rest solely on scientific evidence. All of the approaches are, however, indirect, imperfect surrogates for the elusive real thing, and therefore none is truly satisfactory. I will first note the most common choices and recount their weaknesses, especially in the context of their application in China. Then I will take a closer look at some recent applications, including both satisfactory quantifications and attempts to value the invaluable.

Approaches to Valuation

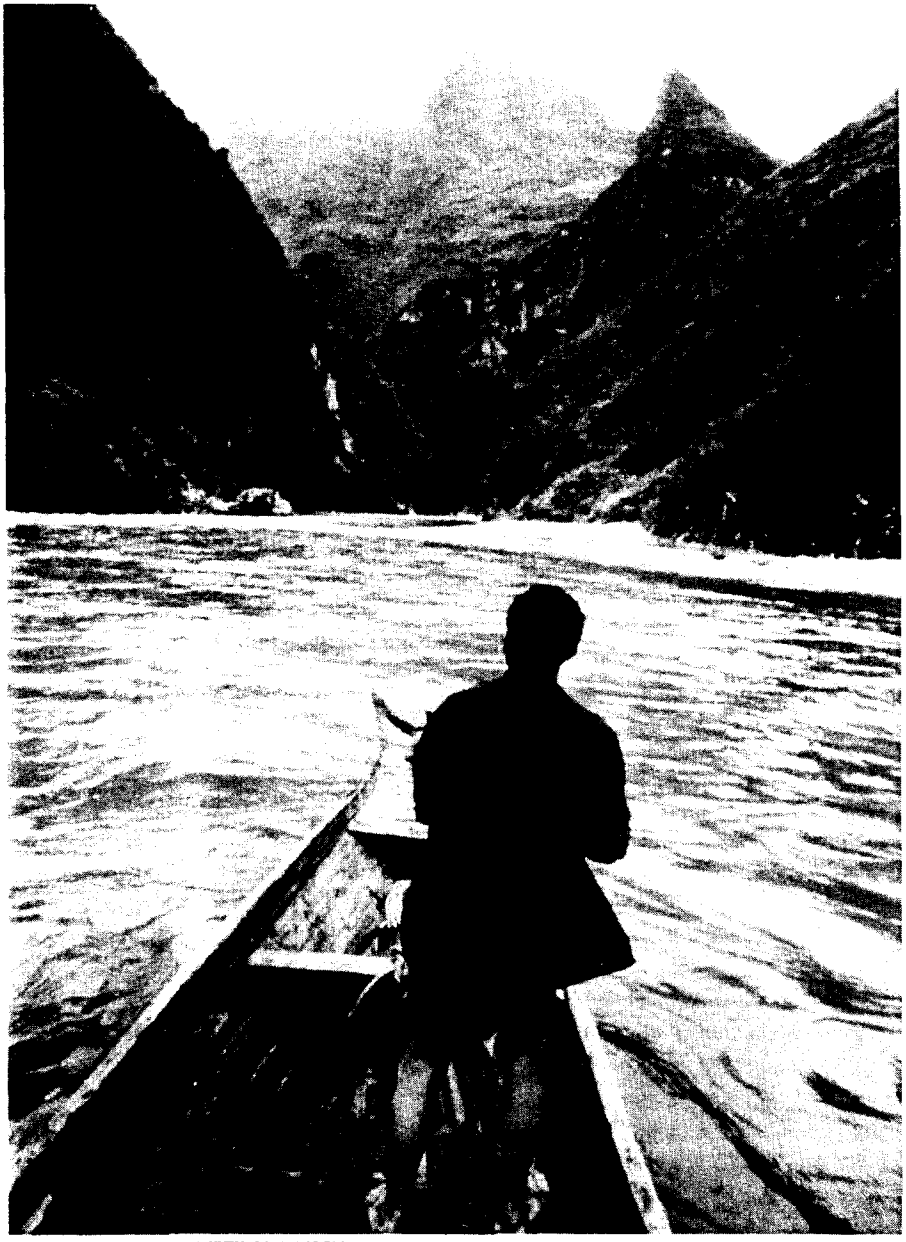
The first broad category of surrogate approaches includes market measures that reflect, incompletely but often very usefully, the value of the sought-after attribute or service. The simplest approach is to calculate the cost of a commercial commodity whose production either has declined or has been totally eliminated by a particular environmental change. These productivity changes can sometimes be assessed fairly easily by looking at trends in such measures as average crop yields, annual timber growth, or fish catches. However, the multifactorial origins of some of these trends may make calculations quite difficult. The direct cost approach may also lead to serious misrepresentations when used in Chinese circumstances. Although the market segment of China's economy has been rapidly advancing, many basic commodities still trade at prices that are heavily influenced by state price fixing. Consequently, valuing an environmental change in terms of the associated commodity loss may make it look exceedingly light compared with another kind of change that affects a commodity whose domestic price is much closer to the free market value.

Two other measures frequently used in assessing productivity declines are loss of earnings and preventive expenditures. In many cases their value may be more appropriate to use than the value of the declining commodity itself. For example, the fish catch may become severely depressed in a lake region affected by acid deposition. However, if most of the fishing is recreational rather than commercial, then the loss of earnings to fishing camp employees and associated service personnel (e.g., reservation agents, bush pilots) or preventive

Given the current preoccupation with the quest for fast accumulation of personal wealth in China, questions about the hypothetical worth of distant forests or river valleys might elicit laughably low answers. (Shown: An oarsman guides his traditional boat down the Yangzi River.)

measures undertaken to limit the damage (e.g., liming of lakes by installation of alkaline matter dispensers on streams flowing into affected lakes) would be expected to express the damage better than the theoretical value of the decreased harvest.

Again, however, not necessarily in today's China. If the remedial outlays require an initial scientific and technical assessment, such costs, usually quite high in the West, may be marginal in China due to the artificially depressed value of Chinese expert labor. Although the situation has been changing since the late 1980s, it will still take many years to develop a relatively free market for such labor. Until that time, technical experts, bound to their jobs by their assigned apartments, will survive on relatively very low salaries thanks to enormous state subsidies for housing, utilities, schooling, and food. Similar concerns apply to indirect valuations, i.e., potential expenditures using replacement values or relocation costs, or surrogate market values, most commonly involving property values, wage differentials, and travel costs.



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The use of surrogate market values also has very limited applicability in China. A hedonic approach to valuation, where people's attitudes about the desirability of natural beauty and a clean environment are taken into account when assessing the value of a nonpolluted environment or the cost of a degraded one, originated with appraisals of property values and air pollution levels in the late 1960s and has been in frequent use since then.[15] This approach has no value in China, however, where the private real estate market is just emerging and an overwhelming majority of urbanites have no way to choose their place of residence. In contrast, wage differentials could be used in many instances if sufficient data were available: higher pay must be offered to attract workers to some degraded areas and to jobs in highly polluted workplaces.

Other approaches with limited usefulness in China center on contingent valuations. These approaches, dominated by the studies of the willingness to pay, are not very meaningful without a reasonable level of

In the final analysis, value judgments and different degrees of willingness to tolerate risk are more important than the best scientific evidence

background information to make broader comparative value judgments. Moreover, given the current preoccupation with the quest for fast accumulation of personal wealth in China, questions about the hypothetical worth of distant forests or river valleys might elicit laughably low answers.

Environmental valuations are also limited by more general problems. First, aggregate cost assessments of environmental pollution and degradation are affected by the degree of coverage, as well as by the uncertainty of the scientific basis of most of our valuations. Another complication centers on the dual nature of many environmental effects: although their positive impact may not be realized for years or even decades, the eventual economic consequences may greatly surpass the cost of any identified negative effects. A recent example is the realization of the role of atmospheric sulfates in regulating global climate.[16] Although the value cannot be pinpointed, the evidence now indicates that the increased generation of sulfates by humans, a development directly responsible for acid deposition over parts of Europe and North America, has also lowered the tropospheric* temperature of the northern hemisphere by an amount roughly equivalent to the increase expected because of rising carbon dioxide concentrations. Obviously, then, sulfates as moderators of global warming would have a vastly greater positive environmental impact than as generators of regional acidity.

Because science is so strongly influenced by social, economic, and political factors in the choice of research goals and the interpretation of complex realities, personal and collective attitudes and preferences make a great difference. On the planetary scale this is best illustrated by the ongoing disagreement among techno-optimists and catastrophists about the carrying capacity of the earth and the ultimate impact of potential global climatic change. On a lesser scale are the controversies about safe to low-level radiation and pesticides.

Indeed, one could argue that most environmental controversies are trans-scientific: in the final analysis, value judgments and different degrees of willingness to tolerate risk are more important than the best scientific evidence. Most fundamentally, the preservation of the maximum possible biodiversity is a moral, rather than a scientific, imperative, and the capacity to take risks has been one of the critical attributes guiding our evolution from a simple hominid existence to machine civilization.

Reasonable Quantifications

Although they are in a clear minority, some valuations of environmental effects can be approached simply and, once basic information is available, calculated with satisfactory accuracy. An example is the quantification of air pollution effects on materials ranging from rails to window curtains. Valuations of accelerated corrosion were among the classic concerns of air pollution impact studies, and the vast literature on this subject is still expanding.[17] Many comparative studies show that, when exposed to acid precipitation, carbon steel and zinc deteriorate up to five to seven times faster in heavily polluted industrial atmospheres and between 10 and 50

* The lowest portion of the atmosphere (10–15 kilometers from the surface) where nearly all cloud formations occur and weather conditions manifest themselves.

percent faster even in cleaner rural areas.

Material damage can thus be estimated by applying the results of long-term corrosion tests to a known stock of exposed metals or by calculating expenses for metal replacement and repairs (rails, roofs, ducts, railings, poles, etc.) in a polluted and in a relatively clean area with comparable stocks of exposed structures.

The benefits of some environmental services can also be partially monetized by calculating the costs of surrogates or remedial actions. Frank Rijsberman presents a number of such assessments for wetland losses caused by possible ocean rise due to global warming.[18] Depending on the site, replacement or reconstruction costs were estimated at U.S.(1990) $3 million to $12 million per square kilometer. Raising barrier islands to protect coastlines can cost from $12.5 million to $25 million per square kilometer, replenishing beaches between $4 million and $8 million per square kilometer, and building levees in urban areas from $10 million to $20 million per kilometer.

The economic effects of some environmentally induced health costs can be estimated with reasonable accuracy as well. For example, the availability of epidemiologic data on the frequency of upper-respiratory morbidity caused by high air pollution levels makes it relatively straightforward to express direct economic costs—combining lost production values or the cost of temporary labor replacement with the value of lost or reduced income—to affected companies and individuals. Nationwide, such costs can be considerable.

Elusive Values or Impossible Challenges?

The two largest groups in the most challenging valuation category are the quantification of economic costs of premature mortality and excessive morbidity and the monetization of lost ecosystemic services, either in absolute terms or in relation to the ecosystem's principal commercial goods.

The estimation of lost future earnings has been common in the field of human life valuation.[19] This is a straightforward approach with predictably disturbing results. Children have lower value than young adults, who are the most valuable people in a society (in the United States, lives of males in their thirties are worth about twice those of men in their early fifties). The lives of the elderly are very cheap indeed, and those of males worth more than those of females; girls' lives are uniformly worth less than boys' lives, women as a group are worth less in every society, and educated and skilled people matter more. Attempts to make these measures more sensible only expose their economic shortsightedness. For example, assuming that women's housework should be valued only in terms of a domestic help ignores the most important role a woman plays in a nuclear family, that is, as a supportive mother who enormously increases her children's chances of becoming well-adjusted, and hence productive, adults rather than burdensome social misfits.

Approaches to valuing human life based on willingness to pay, including insurance value or the value of investments designed to prevent the loss of life, are no less problematic. Terminology ("value" being such a loaded term), perception (a spectrum spanning the belief in the invaluable sanctity of all life to the view that specific monetizations are both possible and desirable), and context (e.g., that most people would be willing to spend more to avert an immediate risk to life than to lower a long-term statistical probability) all play major roles in approaching this challenge.[20]

Satisfactory valuations of excessive incidence of sickness (morbidity) are not much easier. Expressing costs in terms of lost income is only a partial solution; a more satisfactory valuation must also include the cost of individual discomfort and suffering. This challenge is made extraordinarily complex by the range of individual responses to pollutants. For example, the response of a person with asthma to elevated concentrations of urban air pollution can range from mild breathing discomfort to a more serious event requiring curtailment of some activities to a life-threatening experience requiring emergency hospitalization. Obviously, it is unsatisfactory to assign, as recent U.S. epidemiological research does, discrete values ranging from $10 to $40 for an asthma attack, $10 to $30 for a restricted activity day, and $3 to $10 for a day with some respiratory symptoms.[21] More important, such largely arbitrary valuations may find little corroboration in asthmatics' own assessments of different levels of discomfort.

Not surprisingly, published estimates of the economic costs of pollution-caused illnesses range widely. The Organization for Economic Cooperation and Development's pioneering study of the cost of acid deposition in Europe estimated that the benefits from avoided morbidity could be as low as U.S.(1980) $280 million or as high as U.S.(1980) $18 billion, a more

Chinese foresters estimate that the combined ecosystemic benefits of mature forests are between 8 and 25 times the profit from harvested timber sales

than 60-fold difference and the principal reason for the study's inconclusive outcome.[22] Because lowered morbidity represented by far the highest gain from effective sulfur dioxide emission controls, the lowest estimate of morbidity benefits was far too low to justify control expenditures (estimated to be at least U.S.(1980) $1.1 billion), whereas the highest figure would have yielded impressively high economic returns given that the cost of even the most stringent controls would not have surpassed U.S.(1980) $3 billion.

Recent benefit/cost studies of air pollution control in the Los Angeles basin have the same inconclusive and questionable outcomes. The total annual health benefits from reduced morbidity were found to be as low as U.S.(1990) $1.2 billion or as high as U.S.(1990) $20 billion.[23] Given the U.S.(1990) $13 billion that may be required to clean up the basin's air, morbidity costs alone can either justify the effort or make it economically unappealing.

F. W. Lipfert and S. C. Morris went to the heart of the problem by arguing that the health benefits of pollution control are usually underestimated because we know (or think we know) how to calculate only a few of them owing to what they termed the "sorry state of our knowledge." These researchers concluded that "the overwhelming uncertainties are not those of economics. Instead, they lie with the fragmentary approach to the epidemiology of community air pollution that continues to be applied to a pressing national problem."[24]

Identical weaknesses characterize our approach to valuing ecosystemic degradation, a change that is categorically very similar to human morbidity. Much as urban populations breathe polluted air over a lifetime, ecosystems suffer long-term exposure to a range of pollutants. Nonetheless, we try to tease out cause-and-effect relationships for a single agent based on short-term studies.

A recent example from China illustrates these difficulties with attribution. The country has fairly reliable figures on the extent of two classes of major natural disasters: droughts and floods. Droughts constitute China's most extensive environmental stress, typically affecting about one-tenth of the densely inhabited territory every year. Since 1970, areas disastrously affected by drought—defined in China as regions in which crop yields are reduced by at least 30 percent compared with a normal year—fluctuated between 2 million and 18 million hectares per year. During the late 1980s, however, the average surpassed 13 million hectares per year, compared with less than 11 million hectares in the late 1970s. How much of this clearly significant increase can be attributed to environmental degradation resulting from human action?

During the 1980s the average area disastrously affected by floods rose to about 5.5 million hectares per year—nearly a 2.5-fold increase compared with the 1970s—and the risks of catastrophic flooding increased in almost every part of China. This trend culminated in the summer of 1991, when floods covered nearly 25 million hectares and disastrously affected almost 15 million hectares, an area nearly twice as large as the previous record. In some areas these floods achieved almost biblical dimensions. In Anhui, for example, 44 million people (of the total of 54.7 million) were affected, and nearly 9 million were marooned in their villages by floodwaters that destroyed more than 1.5 million

homes.[25] The direct nationwide economic costs of the 1991 floods were estimated officially at RMB(1991) 72.5 billion.[26] Many Chinese scientists linked the extraordinary scale of this catastrophe to deforestation and soil erosion in the upper parts of the Yangzi basin. In this case, much more than in relating droughts to man-made changes, there is clearly a strong factual basis for linking the two kinds of events—but, again, no more than an educated guess can be made regarding the share of this excessive flooding attributable to human actions.

Still, attributions are only a small part of the difficulty in valuing environmental services. Assuming that 40 percent, instead of 20 percent, of a particular impact is caused by human action will double the cost, but the estimate of the cost itself may span a tenfold difference! Not surprisingly, therefore, most published valuations of environmental costs have been challenged, a fact which makes policymakers cautious to accept any conclusions: choosing sides may have enormous economic implications. Two recent examples, both dealing with the environmental costs of energy extraction and conversion, illustrate this point.

First, pioneering studies in highly environment-conscious Germany estimated the external environmental costs of electric power to be of the same order of magnitude as the internal electricity generation costs.[27] This finding was of great policymaking significance in a nation concerned about its environment in general (the first Western nation with a politically influential environmental party), actively engaged in debates about the future of energy alternatives (opting to get out of nuclear generation), and worried about the survival of its legendary forests. If acted upon, these conclusions would have required annual expenditures of billions of marks. However, detailed critiques of these studies exposed their many methodo-logic and data weaknesses and offered very different estimates, which put the reasonably quantifiable environmental costs of coal-fired electricity at only between 3 and 17 percent of total generating costs.[28]

The second case deals with the true cost of Appalachian coal. Robert Cullen concluded that a complete accounting of the external environmental costs of coal mining and combustion would increase coal prices from about U.S.(1993) $20 per ton to around $200 per ton, a shift that would make many alternative energy sources highly competitive.[29] In disputing this conclusion, E. M. Trisko cited the results of site-specific modeling of the environmental impact of new coal-fired power plants done at the Oak Ridge National Laboratory, which set the actual damages from coal mining and combustion at just 0.1 cent per kilowatt-hour.[30] This is a totally negligible burden compared to the average residential price of 8 cents per kilowatt-hour and is orders of magnitude below Cullen's estimate. In a rebuttal, however, Cullen drew attention to one of the most important limitations of using internalized costs to reconstitute environmental services: the enormous mismatch of qualities. As he rightly notes, anyone who believes that coal-mining successfully internalizes critical environmental costs has not walked through the scrubby growth or fished the sterile streams found in even thoroughly reclaimed strip-mining sites.[31]

Further complications are introduced by difficult-to-defend differentials in understandably dissimilar valuations. Although it makes sense that an additional ton of air pollution emitted in the Los Angeles basin should be penalized more than one emitted in Massachusetts, charges imposed by utility commissions on coal-fired electricity generating stations are U.S.(1993) $23,490 per metric ton of sulfur dioxide in the first location—but only $1,700 in the second. The cost of additional nitrogen oxide emissions, however, is only about four times higher in Los Angeles than in Boston.

Perhaps the only solid conclusion about the monetization of ecosystemic effects is to point out generally large, but highly uncertain, disparities between valuations limited to lost goods and those embracing one or more ecosystemic service functions. Many recent examples can be cited to illustrate this obvious gap. In the first, an estimate of the annual economic cost of diminished wood harvests owing to acid deposition in former West Germany was put at DM(1985) 1.7 billion to DM 6.3 billion, whereas lowered leisure and recreation benefits were estimated to total DM(1985) 2.3 billion to DM 11.3 billion per year.[32] Chinese foresters estimate that the combined ecosystemic benefits of mature forests are between 8 and 25 times the profit from harvested timber sales.

Likewise, a study done for the Changbaishan natural reserve in Jilin[33] concluded that if a forest's water storage capacity was replaced by an equally large reservoir, if erosion was prevented by terracing of slopes, and if pesticides were used to equal the value of services provided by forest-sheltered insect-consuming birds, then the reserve's worth would be equal to RMB(1990) 9.27 billion, or about RMB(1990) 49,000 per hectare.

The dynamics of China's economy in the early 1990s greatly resembles that of the American expansion a century ago

The total would increase substantially with the inclusion of the forest's contribution to climatic controls and preservation of biodiversity.

A study prepared by the Mitsubishi Research Institute for the Japanese Ministry of Agriculture, Forestry, and Fisheries estimated that the "land and environmental preservation function" of rice paddies is worth ¥(1990) 12 trillion a year, or three times the total value of Japanese rice production.[34] This estimate of environmental benefits considered that wet fields have a long-term beneficial effect on soil quality; prevent widespread nitrogen pollution of ground and surface waters, which, given Japan's high rates of fertilization, might otherwise occur due to nitrogen leaching; reduce the risk of floods; provide habitats for a number of beneficial species; and even beautify the landscape.

To end this litany of troubles, every long-term valuation is also beset by the fundamental dilemma of discounting. The choice of the discounting rate is naturally crucial. Although a truly humanistic approach might reject any discounting of human lives, every society is engaged, implicitly and explicitly, in such a practice. In the United States there is now a legal requirement to discount human lives when calculating the benefits of environmental controls designed to save them. For example, in October 1991, the U.S. Court of Appeals overturned the Environmental Protection Agency regulations relating to a number of asbestos-containing products because, among other things, the agency did not discount the lives saved in the same way it discounted the future costs of controls. The court, at least as far as the public perception is concerned, was right. A Resources for the Future poll of 2,600 Americans clearly showed that people do not feel that a life saved in the future is equivalent to a life saved today.[35] The respondents were strikingly present-oriented; they considered 6 lives saved 25 years in the future as equivalent to one life saved today, with the ratio increasing to 11 for a 50-year period and to 44 for a period of 100 years.

These preliminary findings are open to all kinds of practical and ethical challenges. They may have a broadly ethnocentric bias: even this limited study revealed that black Americans had significantly higher discount rates for saving lives; that is, one life saved in the present was worth even more future lives than indicated in the overall results. The findings may also be quite different in different nations and at different times of economic development. Perhaps the most fundamental problem is one of ethical long-term policy-making: is it wise to discount lives so steeply when life expectancies in rich countries now surpass 70 years and when many newly built infrastructures and newly introduced processes with environmental effects will be with us for many decades? Even broad agreement on this point merely introduces new uncertainties: if lower discount rates are needed, how low should we go?

Despite these difficulties there is no doubt about the desirability of environmental cost accounting and the need for its widest possible application. Although in some Western settings this task can be approached with a good deal of sophistication, the enormous data limitations in China restrict most attempts to relatively simple calculations. Still, even such estimates should be more useful than mere qualitative assertions.

ENVIRONMENTAL POLLUTION IN CHINA

Although China has the capability to launch foreign communication satellites and to export increasingly more sophisticated electronic equipment, in many other ways it is still in the midst of the first phase of rapid industrial development. This phase is characterized by strong demand for primary energy, rising production of metals (annual steel output has just topped 90 million metric tons and is closing on the Japanese total), expansion of basic chemical industries, mass manufacturing aimed at supplying basic household needs to still largely rural populations, and movement of millions of migrants from the countryside to the cities. Thus, whereas modern techniques have changed the facade, the dynamics of China's economy in the early 1990s greatly resembles that of the American expansion a century ago.

With this expansion goes environmental pollution of every imaginable kind.[36] Although modern techniques have intervened and virtually all of China's large electricity-generating plants are now equipped with fairly efficient electrostatic precipitators (to remove particulates) and new refineries with adequate water treatment, most of China's coal is burned without any emission controls, most of its wastewater does not receive even the simplest treatment, and most of its solid wastes are simply dumped haphazardly.

The seriousness of China's pollution problems is substantiated by the public perception of environmental hazards. A recent opinion survey[37] found that, among 20 common environmental hazards, people ranked water and air pollution as the most serious hazards after earthquakes and floods. People with a science or engineering education, however, ranked water and air pollution as the most dangerous environmental risks in China.

Chinese publications and statistical sources now provide enough information to quantify all of the most important pollution streams, to understand their basic spatial distribution, and to offer alternative forecasts of their growth or decline during the remainder of the 1990s. Only a few unsystematic studies and appraisals, however, relate these flows and rates to environmental effects and costs. Chinese economists and environmental scientists have yet to embrace the new resource valuation with the enthusiasm of some North American and West European scholars. Consequently, this valuation exercise must rely on commonly accepted techniques, such as changes in productivity, costs of illness, and preventive expenditures. Even this conservative approach to the valuation of China's environmental problems must rely on cumulative assumptions and hence can aspire to nothing more than a narrowing of the uncertainties with regard to air pollution, water pollution, and management of solid wastes.

Air Pollution

China is now the world's largest producer and consumer of bituminous coal: both its nationwide output and domestic consumption have been above 1 billion metric tons since 1989. In 1992 particulate emissions totalled just over 14 million metric tons, and sulfur dioxide releases reached nearly 17 million metric tons (Table 1).

In general, Chinese coals are of reasonably good quality. Their typical ash content is about 10 percent, and statistics for large state mines show that the average sulfur content of commercial coal is just 1.04 percent.[38] Only some southern coals, notably those from Sichuan and Yunnan, have unusually high (up to 5 percent) sulfur content. Consequently, the country's average gross air pollution emission factors are not unusually high. But the ways in which most of the coal is burned are increasing both outdoor and indoor concentrations and are creating some of the world's highest exposures to particulate matter, sulfur dioxide, and benzopyrene.* (See Table 1.)

Table 1. Recent totals of coal combustion and total suspended particulates (TSP) and sulfur dioxide (SO_2) emissions in China

Year	Coal combustion (millions of metric tons)	Total emissions TSP (millions of metric tons)	Total emissions SO_2 (millions of metric tons)
1988	994	14.6	15.2
1989	1,034	14.0	15.6
1990	1,055	13.5	15.0
1991	1,104	13.9	16.2
1992	1,150	14.1	16.9

Source: Various issues of *China Statistical Yearbook* (State Statistical Bureau) and personal communication with China's National Environmental Protection Agency.

Chinese emission factors per unit of delivered energy are extraordinarily high

Chinese coal production of the early 1990s was about equally split between a few hundred large, state-owned, centrally administered mines and tens of thousands of small, locally (collectively or privately) owned surface and shaft operations. More than half of all state-produced coal and virtually all coal from local mines is burned without any preparatory cleaning and sorting and therefore contains very high amounts (at least 30 percent but often up to 50 percent) of incombustible matter. In addition, most of this fuel is burned in the small, outdated, and hence highly inefficient boilers that fuel small industries, service establishments, and housing estates and commonly convert less than 60 percent of fuel into useful heat; in even less efficient household stoves, which are typically less than 30 percent efficient; and, most wastefully, in steam locomotives, which convert less than 10 percent of the fuel into energy.

As a result of these low efficiencies, Chinese emission factors per unit of delivered useful energy are extraordinarily high. The high density of Chinese cities, common commingling of residential and industrial areas, releases of uncontrolled emissions from low chimneys, residential crowding, improperly vented household stoves, and the use of smoky biomass fuels in rural areas are the most important additional factors responsible for both extremely high short-term concentrations of outdoor and indoor air pollutants and harmfully high long-term levels.

Concentrations and Exposures China's national air quality standards for the two most important pollutants, total suspended particulates (TSP) and sulfur dioxide, vary to a surprising degree. In China, the strictest standards are for the cleanest natural areas, the medium level for urban residential and rural settings, and the highest permissible concentrations for industrial zones and areas of heavy traffic. The Chinese norms for particulates are considerably higher than the maximum daily averages recommended by the World Health Organization (WHO), which represents a broad international consensus (Table 2). No matter which yardstick is used, typical Chinese exposures are excessive. Actual exposures are so high that the daily average of annual pollution levels is often as high or higher than the level that WHO recommends should not be exceeded more than seven days out of the year.

The systematic measurement of urban air pollution in China began in 1981 in seven cities and was expanded to nearly 50 urban areas by the end of the decade.[39] Not surprisingly, there were many early problems with analytical reliability and data continuity, and even the largest cities have only a handful of monitoring locations. Still, the consistency of the accumulated record allows us to conclude that every major northern city and many urban areas in the south have been exposed to excessive concentrations of particulates and sulfur dioxide.

Mean annual particulate levels in Beijing—hardly the most polluted city in China—are typically between 400 and 500 micrograms per cubic meter. WHO's daily particulate maximum of 230 micrograms per cubic meter, which is not to be exceeded during

* Particulates are solid or liquid particles suspended in the air that cause or worsen respiratory illnesses; sulfur dioxide reduces visibility, speeds the corrosion of some metals and paints, and increases the acidity of rain; benzopyrene is a known carcinogen.

Table 2. Comparison of Chinese and international guidelines for maximum daily permissible outdoor levels of total suspended particulates (TSP) and sulfur dioxide (SO_2)

		TSP	SO_2
		(micrograms per cubic meter)	
Chinese standards (annual averages)			
Level I	Industrial and heavy traffic areas	500	100
Level II	Urban residential and rural areas	300	60
Level III	Nature preserves; conservation zones	150	20
World Health Organizations guidelines (annual averages)		60–90	40–60
World Health Organization daily maximums*		150–230	100–150

*Not to be exceeded more than 2 percent of the days in a year.
Source: Cao (1989:765).

Every major northern city and many urban areas in the south have been exposed to excessive concentrations of particulates and sulfur dioxide

more than 2 percent of the days in a year, was exceeded more than half the time at some locations and almost every day at a western Beijing site in 1989, with peak daily concentrations surpassing 1,000 micrograms per cubic meter. All major northern cities have similar annual particulate means. The worst-off cities (Taiyuan and Linfeng in Shanxi, Lanzhou in Gansu, Mudanjiang in Heilongjiang) recorded annual particulate means above 600 micrograms per cubic meter during the 1980s. The major southern cities are somewhat cleaner, with annual means of approximately 300 micrograms per cubic meter, but such values are still multiples of WHO guidelines recommending annual averages of no more than 60–90 micrograms per cubic meter.

For sulfur dioxide, the guidelines specify means of no more than 500 micrograms per cubic meter for 10 minutes, 350 micrograms for one hour, 100–150 micrograms for 24 hours, and 40–60 micrograms for one year. Annual averages of sulfur dioxide concentrations have been above these levels in every northern Chinese city and, because of the high sulfur content of many southern coals, also in many centers south of the Yangzi. Beijing's annual means have run from 80 micrograms per cubic meter in the cleanest suburbs to twice that much in the most polluted locations. These are low levels compared with annual means of more than 400 micrograms per cubic meter in Taiyuan and Lanzhou and over 300 micrograms in Linfeng, Chongqing (in Sichuan), and Guiyang (in Guizhou).

No detailed breakdowns of populations exposed to different levels of particulates and sulfur dioxide are available, but, based on available urban measurements and the latest census figures, I estimate that at least 200 million Chinese are exposed to annual particulate concentrations of above 300 micrograms per cubic meter, and at least 20 million are exposed to twice that level (Table 3). These are extraordinarily high exposures, currently comparable only to some Indian, Russian, and Central European levels and resembling the urban values in West Europe and North America of two to three generations ago.

Extending these estimates to rural populations is more problematic. Although typical outdoor air pollution

Table 3. Approximate distribution of urban population exposures to total suspended particulates (TSP)

Mean annual TSP concentration (micrograms per cubic meter)	Exposed urban population in 1990 (in millions)
< 100	30
100–200	50
200–300	50
300–400	80
400–500	60
500–600	40
600 >	20

Source: Author's estimates are based on the cited air quality monitoring data and on the official figures of China's urban population.

During the late 1980s chronic lung diseases accounted for about 25 percent of all deaths

levels in the Chinese countryside may be fairly, or often even very, low, the recent rapid expansion of cooperative and private industries has introduced many uncontrolled sources of air pollution into rural areas, causing locally high pollution levels. More important, rural inhabitants are repeatedly exposed to very high levels of indoor air pollution. Although the lack of representative studies breaking down time spent outdoors and indoors in various provinces or for different population groups makes it impossible to calculate typical exposures, the available information makes it clear that a significant share of China's rural population is exposed to particulate concentrations in excess of the national standard and that 100–200 million persons in rural areas may be breathing air that is nearly as polluted as that in large cities.

Air Pollution and Human Health Despite decades of intensive research on the effects of air pollution on human health, including numerous laboratory experiments with animals and hundreds of epidemiologic studies, only a few basic generalizations are possible. The statistical relationship between air pollution and increased incidence of upper respiratory infections, chronic obstructive lung diseases (bronchitis, asthma), and lung cancer have been repeatedly demonstrated in many affluent nations; the same effects must be expected in China. High air pollution levels also contribute to reduced lung capacity in children.[40]

The heavy toll of China's air pollution on human health is readily seen by the high incidence of chronic lung diseases: during the late 1980s these diseases accounted for approximately 25 percent of all deaths, resulting in a standardized rate of more than 160/100,000, or five times the U.S. average. Obviously, not all of this effect can be attributed to outdoor air pollution. Smoking is a critical contributing factor in China, and tens of millions of urban, and hundreds of millions of rural, Chinese are also exposed to undesirable levels of indoor air pollution from improperly vented stoves.[41]

This effect is particularly strong among Chinese females. The country's ratio of male/female lung cancers is about 2, much lower than the ratio of smoking incidence. An epidemiologic survey in Guangdong revealed that smoking alone cannot explain the high incidence of lung cancer in women.[42]

In households that cook with raw coal, or with poor quality briquettes burned in simple stoves, indoor concentrations of pollutants are frequently much higher than the outdoor levels of the pollutants. (Shown: Man delivering charcoal briquettes used for heating and cooking in the home.)

STILL PICTURES

In households that cook with raw coal, or with poor-quality briquettes burned in simple stoves, indoor concentrations of sulfur dioxide, particulates, and benzopyrene are frequently much higher than the outdoor levels of these pollutants—and their peaks correlate with cooking hours. Similarly, indoor air pollution levels from the burning of various biomass fuels in rural areas are almost always much higher than the outdoor concentrations. Although it is impossible to offer any representative means, available measurements of Chinese indoor air pollution indicate that particulate concentrations of around 500 micrograms per cubic meter are quite common and that short-term levels can reach many thousands of micrograms per cubic meter.[43] These effects are particularly important in northern China, where people spend much more time indoors than in the south and where stoves are also used for heating.

A further complication is that the chemical processes underlying air pollution's effects on human health and the synergetic action of many pollutants are very poorly understood. With particulates, whose standards are based on the total mass of the fraction able to penetrate human lungs (that is, particles of less than 15 micrometers in aerodynamic diameter), it is not known if the effects depend on specific chemical components or only on total exposure. With sulfur dioxide there are also major uncertainties in extrapolating conclusive long-term studies of animal exposure to humans.

We must be mindful of these complexities when evaluating the recently accumulated epidemiologic record, which suggests that increases in human mortality and morbidity have been associated with particulate levels significantly lower than those previously thought to damage human health.[44] Moreover, recently published time series tracing the effects of particulates on daily mortality do not seem to show any minimum threshold level but rather indicate increases in mortality rates of between 0.3 and 1.5 percent (average about 0.9 percent) for every 20 micrograms per cubic meter increase in ambient particulates. If it withstands critical evaluation, this new evidence would require tightening of existing outdoor air standards. Obviously, it would also have significant economic consequences for a number of industries, and it would make particulate matter alone responsible for a large share of respiratory diseases and for a very high number of premature deaths in China, as well as in other highly polluted countries.

These complex realities make it obvious that all of the following estimates are highly tentative. Assuming that about 500 million Chinese—half in urban areas (Table 3) and half in rural households—are exposed to particulate levels above 200 micrograms per cubic meter (with actual exposures mostly between 300–500 micrograms per cubic meter), that the rest are exposed to no more than 200 micrograms per cubic meter, and that there is roughly 1 percent increase in mortality for every 20 micrograms per cubic meter, then no less than 10–15 percent of chronic lung diseases should be attributable to air pollution. With annual mortality at 160/100,000, this would amount to 180,000 to 270,000 persons per year. With average hospitalization costs at RMB 800 per person, the minimum costs would be RMB 140 million to RMB 220 million. The average loss of

The costs of respiratory disease induced or aggravated by air pollution is high even when using conservative assumptions

at least one year of productive life (at RMB 2,200) would add RMB 400 million to RMB 600 million.

The cost of respiratory disease induced or aggravated by air pollution—e.g., higher incidence of bronchitis, pneumonia, and asthmatic attacks—is high even when using conservative assumptions. Taking into account only economically active adults (roughly 250 million persons in areas with high particulate and sulfur dioxide levels), and assuming that air pollution will cause just one case of respiratory disease per year in 66 to 80 percent of the affected population and that an average incident will require no more than two to three days of absence from work, the cost totals RMB 2.5 billion to RMB 4.5 billion. Monetizing personal discomfort, even at just RMB 5 per day of heavy coughing or per asthma attack, would roughly double these totals.

A conservative attribution of lung cancer to air pollution—necessary in view of the high rates of smoking in China—would be no higher than 15 to 20 percent of all cases, or approximately 15,000 to 25,000 deaths per year. With average treatment costs of RMB 5,000 per person and a mean of 12 years of lost earnings at about RMB 2,300 per year, the annual cost would come to RMB 500 million to 800 million. Obviously, monetization of personal suffering would more than double these values. Attribution of only about 5 percent of all cardiovascular deaths to air pollution (45,000 cases) given average hospitalization costs of RMB 1,700 and two years of lost earnings would total at least RMB 270 million. These highly conservative estimates (excluding costs of personal suffering) add up to RMB 3.8 billion to RMB 6.5 billion. For comparison, a 1990 study by Guo Xiaomin and others estimated the annual health cost of China's air pollution at RMB 3.75 billion for the year 1985.[45]

Other Effects of Air Pollution Other categories commonly included in evaluations of the economic burdens of excessive air pollution include damage to materials (e.g., faster corrosion of metals) and buildings, lowered yields of crops exposed to high concentrations of particulates and gases, and higher costs of household cleaning. The last effect may seem the least important, but it can add up to considerable sums spent on additional cleaning chores (washing windows, floors, window coverings, clothes) and purchase of soap and detergents. A Beijing survey showed that even suburban families spent nine more days on household cleaning per year than families living in unpolluted rural areas. With at least 50 million families exposed to high levels of particulate pollution, the additional cost of household labor (at just RMB 5 per day) would amount to RMB 2.25 billion. Purchases of cleaning products and faster deterioration of fabrics could increase this total by at least 20 percent, to about RMB 2.7 billion.

Crops are usually affected only by very high particulate and sulfur dioxide concentrations, but such levels are, unfortunately, found in many of China's urban and industrial areas. The Ministry of Agriculture estimated that, in 1985, approximately 800,000 hectares of suburban vegetable fields were exposed to heavy air pollution. At an average loss of 10–15 percent of the annual yield of 40–50 metric tons per hectare, and the price of RMB 500 to RMB 600 per ton, air pollution would result in annual losses of about RMB 1.6 billion to RMB 3.6 billion. About 10 percent of

China's 2 million hectares of orchards are also affected: with yields estimated at an average of 15 metric tons per hectare, loss to pollution at 10–15 percent, and fruit prices at RMB 1,500 per metric ton, the annual loss would amount to RMB 450 million to RMB 650 million. The combined cost of vegetable and fruit losses would then be between RMB 2.1 billion and RMB 4.3 billion

Because of inadequate data, a 1990 study by Guo Xiaomin and others estimated the damage done by air pollution to materials and buildings—about RMB(1985) 4.5 billion—in a highly questionable, indirect way: they assumed that the ratio of health damage to material damage was the same as in American studies of the 1960s and 1970s, and they simply multiplied their estimate of health damage caused by air pollution by an appropriate factor. A more realistic indirect approach is to assume that the accelerated corrosion of metals and the need for more frequent painting and replacement of exposed materials equals 2–4 percent of all capital investment in the industrial sector, a rate consistent with findings in a number of industrial countries. In 1990, this would have amounted to RMB 2 billion to RMB 4 billion.

Acid Deposition Chinese surveys of acid deposition started in 1982, and the nationwide monitoring network has increased to about 300 stations since then. Results show an interesting, and for northern China a fortuitous, dichotomy of rain acidities.[46] Despite the North's heavy dependence on coal combustion, the alkaline matter originating from local barren surfaces and neighboring deserts and the release of ammonia from the region's alkaline soils, which have pH levels of 7–8,* combine to provide a high buffering capacity and to counteract any danger of acidification.

The average pH of Beijing precipitation has been about 6.8. This is almost neutral; in fact, it is less acid than the cleanest rain falling on remote ocean areas where acidification caused by atmospheric carbon dioxide results in an average pH of about 5.6. Beijing measurements of airborne particulates show a combined level of alkaline elements (calcium, potassium, magnesium) that is about twice as high as the level of acidifying compounds (sulfates and nitrates).

In contrast, the soils of the vegetated areas south of the Yangzi are commonly acidic (pH 5–6), and the combustion of coals with high sulfur content generates locally serious, and spreading, acidification. Southeastern Anhui province and northeastern Jiangsu have precipitation pH below 5.0 (lower values represent higher acidity), but the acidities are highest in the much larger contiguous area in the southwest that includes Sichuan, Guizhou, Guangxi, and Hunan. Moreover, all of China's large southern cities now have precipitation with acidities below pH 4.5, and the lowest recorded values (as low as 3.06 in Liuzhou in Guangxi and 3.15 in Guiyang in Guizhou) match the levels in the most acidified parts of Western Europe.

Compared to the many studies of acid deposition in Europe and North America, Chinese assessments have been modest, and there is no conclusive research on which to base the extent and degree of damage to crops and forests.[47] For the benefit of those unfamiliar with the history and accomplishments of Western acid deposition research, however, I must hasten to add that those efforts had not provided such a basis either—despite more than two decades of studies costing close to U.S.$1 billion.

The most detailed appraisal, the U.S. National Acid Precipitation Assessment Program (NAPAP), found—contrary to previously widely held impressions—that environmental damage from acid rain in the United States is limited in extent, severity, and resources affected.[48] NAPAP studies confirmed harmful effects on a limited number of lakes, streams, and forests, as well as some damage to structural materials, e.g., somewhat faster deterioration of galvanized steel, masonry, and stone. However, the assessment found no negative effects on agriculture and only speculative effects on human health. For example, acid aerosols may be causing an increased incidence of asthma and bronchitis among sensitive persons, and acidification of soils may make some metals (i.e., mercury and aluminum) available for plant uptake or lead to higher levels of absorption of these elements into drinking water. NAPAP offered no summaries of the economic cost of acidification, and its findings "are such that a wide range of policy actions could be supported depending on the values ascribed to these physical effects, and especially how risk-averse the decision maker was to different uncertainties."[49]

This inconclusive outcome is nothing new to students of acidification. In 1981, an OECD study of European sulfur dioxide emissions compared the costs and benefits of controls based on different assumptions about damage and control measures. As

* The pH scale expresses the acidity or alkalinity of a solution on a scale of 0 to 14, where less than 7 represents acidity, 7 neutrality, and more than 7 alkalinity.

noted above, however, largely because of a huge range of estimates for economic benefits of lowered morbidity (ranging from U.S.$280 million to more than U.S.$18 billion) the study could not even conclude if the total control costs, put at between U.S.$1.1 and $2.7 billion, would bring an enormous benefit or represent a major loss.[50]

With the NAPAP experience in mind, I suggest that the economic cost of acid deposition in China—given its currently limited spatial extent and environmentally precluded possibility to affect the arid North—is relatively small in terms of crop and material damage, but it may have a growing effect on the productivity of forests in a few heavily acidifying localities in Sichuan and Guangxi. If only 1 million to 2 million hectares of southern forests suffer a 10 percent loss in average productivity, the annual cost in terms of lost timber harvests would be about RMB 800 million to RMB 1,700 million (U.S.$96 million to $204 million). However, contributions of sulfates and nitrates to higher particulate exposures may have considerable adverse health effects throughout the country.

Water Pollution

Chinese statistics chart a steady increase in the total volume of waste water, from 29 billion cubic meters in 1981 to 35.9 billion cubic meters in 1992, with the share of industrial wastewater declining steadily as cities expand and more urban households are connected to sewers. Some forecasts see more than a doubling of the 1990 figures by the year 2000, to almost 78 billion cubic meters of wastewater.

Many nationwide studies done during the 1980s offer a litany of depressing conclusions about water pollution in China

Many nationwide studies done during the 1980s offer a litany of depressing conclusions about water pollution in China.[51] A survey of 878 major rivers found that 82 percent were polluted to some degree, more than 20 percent to the point that it was impossible to use their water for irrigation; more than 5 percent had no living fish. Four-fifths of China's surface water in urban areas was contaminated, and in only 6 of China's 27 largest cities was drinking water quality within state standards; underground water did not meet state standards in 23 of these cities.

Provincial and local surveys have documented even greater problems. In Shanxi, China's leading coal-mining province, 87 percent of all rivers and canals were polluted in 1990. Many lakes in intensively farmed provinces south of the Yangzi are choked with dense growths of algae, which feed on the large inflows of nutrients leached from the heavily fertilized farmland. When the algae decays, depleting the water of oxygen, the lakes cannot support other aquatic life, be used for recreation, or, without expensive treatment, supply drinking water.

Municipal wastes are commonly released untreated even in large cities. Of the 8,000 metric tons of human waste generated in Shanghai, half is discharged into the Yangzi and the Hangzhou Bay.[52] The Songhua River in Jilin and Heilongjiang contains tens of tons of mercury, the legacy of pre-1977 uncontrolled releases that caused waterborne mercury concentrations higher than in the Minamata Bay in Japan.[53]

The mushrooming of small and mid-size factories outside large cities has also carried increasing volumes of industrial water pollution into China's countryside. In the coastal Jiangsu province (surrounding Shanghai) there is now about one new enter-

The mushrooming of small and mid-size factories outside large cities has also carried increasing volumes of industrial water pollution into China's countryside. (Shown: A coal-fired cement factory in Sichuan Province.)

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prise per square kilometer. Industrial wastes released into local lakes, rivers, and canals contaminate water that is used for drinking (about half of China's population draws its drinking water from surface sources), animal care, and irrigation. No one knows with satisfactory accuracy how much unprocessed waste these rural enterprises release annually. The most common uncontrolled pollutants are phenols,* heavy metals, and organic wastes from food processing. Residues of heavy metals such as chromium, lead, and cadmium are particularly high in many staple crops because peasants use canal and river mud, where such elements accumulate, as organic fertilizer. River mud used as a fertilizer in Jiangsu was found to contain up to 25 micrograms of cadmium per kilogram and more than one gram of lead per kilogram.[54]

Nitrogen Leaching Pollution of water with nitrates from high levels of fertilization has so far been a surprisingly minor problem but is bound to get worse. China is now the world's largest consumer of synthetic nitrogen fertilizers. Average annual applications, which were lower than U.S. levels until the late 1960s, have surpassed 200 kilograms of the nutrient per hectare, nearly four times the U.S. mean. This means that, in intensively cultivated, double- and triple-cropped areas, the rates are above 300 kilograms, and even above 400 kilograms of nitrogen per hectare. With the addition of animal and human wastes, such loadings will almost certainly lead to higher water contamination.

Both the U.S. and European experiences illustrate this risk. The Mississippi, whose watershed receives about 40 percent of all fertilizers applied in the United States, had fairly low and constant nitrate levels between 1905 (when monitoring started) and the early 1970s. Since then, however, the typical nitrate concentrations have

* A white, crystalline, water-soluble, poisonous mass obtained from coal tar or a hydroxyl derivative of benzene; also called carbolic acid, hydroxybenzene, oxybenzene, phenylic acid.

increased more than fourfold.[55] Similarly, the Dutch have used more nitrogen fertilizer than any other country for decades, and nitrate concentrations in their drinking water started to rise sharply during the early 1970s; a decade later they surpassed the maximum recommended by the European Union, which, at 25 micrograms of nitrate per liter, is 2.5 times higher than the U.S. standard—and by the mid-1980s they were above 40 micrograms of nitrates per liter.[56]

Given the high levels of China's inorganic and organic nitrogen applications, elevated nitrate levels must already exist in many intensively fertilized locales, and a larger-scale take-off of groundwater loadings may be expected during the next decade or soon after. The well-documented health effects of high nitrate loadings include potentially life-threatening methemoglobinemia among infants* and a higher risk of stomach cancer among adults. High nitrate loadings also contribute to eutrophication, the excessive algal blooms whose subsequent decay deprives affected waters of most of their oxygen supply and kills fish and other vertebrates.

Water pollution has caused a variety of local and nationwide economic losses

Economic Effects Water pollution has caused a variety of local and nationwide economic losses. China's annual catch of natural freshwater fish is now only about 25 percent above the level reached in the late 1950s. Water pollution from cities and farm chemicals has also increased the risk of damage to China's growing pond and lake aquaculture industry. These episodes may have serious economic effects: By 1990, shrimps and prawns were cultured on about 250,000 hectares, with a total harvest surpassing 150,000 metric tons; a growing share of the harvest was exported, mainly to Japan and the United States.[57]

A nationwide survey of potential fish production lost due to water pollution came up with a total of 150,000 metric tons in 1985, worth RMB(1985) 260 million.[58] The 1985 study used average prices of just RMB 1 per kilogram of aquatic products and assumed that the fish catch is lowered by an average of 33 percent in polluted waters. Applying the same yield-reduction share to freshwater fish from heavily polluted streams and ponds (at least 10–15 percent of the 5.5 million metric-ton total) and assuming an average cost of RMB 5 to RMB 6 per kilogram (prices of aquatic products rose sharply between 1985 and 1990), the loss totals 180,00 to 270,000 metric tons, or the equivalent of RMB 900 million to RMB 1,600 million. Applying similar rates to cultured seawater products would add at least RMB 200 million, for a total cost of RMB 1.1 billion to RMB 1.8 billion.

The total cost of polluted water to animal husbandry (e.g., increased mortality, higher incidence of tumors) was estimated at RMB 117 million for the year 1985. Assuming no greater extent of that problem and adjusting just for higher meat, egg, and milk costs yields an estimate of RMB 20 million to RMB 300 million by 1990.

Water pollution also has a significant health impact on humans. Polluted water has been a major contributing factor to steadily growing rates of cancers of the liver, stomach, and esophagus. Studies in the worst affected localities found the incidence of cancers of the digestive system to

* Methemoglobinemia, also known as blue baby syndrome, is characterized by a reduced ability of the blood to carry oxygen.

In 1985, the shortfall of industrial water caused by pollution was put at 1 billion metric tons

be 3–10 times higher than in unpolluted places; other adverse health effects include liver enlargement, anemia, skin diseases, premature hair loss, congenital deformities, and waterborne infectious diseases. Water pollution has helped make viral hepatitis and dysentery the two leading infectious diseases in China, with annual incidence levels of about 110 cases per 100,000 and 80 cases per 100,000, respectively. The economic burden of these two diseases is high even when calculations are limited to lost earnings and the cost of hospital stays. If only one-half of the reported incidence is attributable to polluted water, additional cases of hepatitis would have amounted to 550,000 and cases of dysentery to 440,000 in 1990. With average hospital stays of 25 days for the former and 10 for the latter, lost wages (at RMB 7.5 per day) would have totalled about RMB 140 million and the cost of hospital stays (at RMB 250 for hepatitis and RMB 80 for dysentery) about RMB 170 million. Labor days lost to home convalescence and the cost of outpatient treatment and drugs could increase the total by 20 to 50 percent, for an aggregate sum of RMB 370 million to RMB 470 million.

These costs are greatly surpassed, however, by those related to liver cancer. Because of difficulties with attribution, I am using a very conservative estimate that ascribes only 50,000 cases of liver cancer per year (less than 4 percent of all Chinese cancer deaths) to water pollution. With average hospital stays of 30 to 40 days and treatment costs of about RMB 3,000 to RMB 3,500, expenditures on institutional care would come to RMB 150 million to RMB 175 million. This total is overshadowed by the value of lost wages: the disease shortens the productive life by an average of 12 years. Undiscounted loss of earnings would be, at RMB 2,000 to RMB 2,500 per year, about RMB 1.2 billion to RMB 1.5 billion, for a total of RMB 1.4 billion to RMB 1.7 billion.

A number of other waterborne diseases should also be included in the assessment. For example, during the 1980s the frequency of roundworm and hookworm infestations among China's vegetable farmers—exposed repeatedly to pathogens and the eggs of parasites in organic wastes—reached, respectively, 93–94 percent and 65 percent.[59] Recurrent diarrhea is common both during dry periods, when water flows in streams and water levels in ponds are low, and during floods, when untreated organic wastes disperse in surface waters. A highly conservative estimate, along the lines of the one made for respiratory illnesses, adds up to a fairly substantial total. Assuming that only half of China's economically active adults (approximately 300 million persons) have a single bout of water-pollution-induced illness per year and require only one to two days to recover, the lost income amounts to RMB 2.2 billion to RMB 4.5 billion. Again, even a very low valuation of personal discomfort would easily double these totals.

Industrial and agricultural production losses range from the impossibility of using polluted water, to additional costs incurred in tapping new resources, and to contamination of foodstuffs. In 1985, the shortfall of industrial water caused by pollution was put at 1 billion metric tons.[60] Even if that total had been reduced by one-third to one-half by 1990, the loss of annual industrial output (Chinese industries need about 250 metric tons of water per RMB 1,000 of added value) would have been between RMB

Contamination of crops by polluted water endangers health and reduces opportunities for export of products

2 billion and RMB 2.6 billion. Shortages of surface water lead to excessive use of ground water, which must be softened before use. Upgrading of 500 million to 660 million metric tons of ground water costs, at roughly RMB 1 per metric ton, another RMB 500 million to RMB 700 million, for a total cost of RMB 2.5 billion to RMB 3.3 billion.

At least 1.5 million hectares of farmland were irrigated with polluted water in 1985, with yield losses estimated at 186,000 metric tons for field crops and 450,000 metric tons for vegetables. As a drop in this total was unlikely by 1990, similar losses would have cost RMB 400 million to RMB 500 million. A much more widespread problem is the contamination of crops, most frequently vegetables and grains, with toxic wastes (excessively high levels of heavy metals or of organic compounds containing chlorine) or excessive concentrations of nitrates. This food pollution endangers health and reduces opportunities for export of products. Even if this contamination causes a loss of only 0.1 percent to 0.15 percent of China's food output (clearly a greatly underestimated total) it would cost between RMB 600 million and RMB 900 million.

Ocean pollution has also been increasing: its most common constituents have been oil (carried by rivers, discharged by ships, and released by offshore oil drilling in Bohai Bay and parts of the East China Sea and the South China Sea), heavy metals, inorganic nitrogen, and benzene hexachloride.* By the mid-1980s about one-third of China's coastal waters were polluted by oil to a degree higher than the standard set for first-class seawater quality; mercury and cadmium were detected in more than 60 percent and 38 percent of samples, respectively.[61] Given the far-flung provenance of Chinese ocean catches, it is impossible to assign a value to the ocean catch lost due to pollution.

Solid Wastes

As expected, the rapid growth of China's industrial production has brought substantial increases in solid wastes, but the total mass of this waste stream is unknown. What is labeled "industrial waste residue" in Chinese statistics contains everything generated by large state-run industries—but nothing produced by the ever-increasing number of township and rural enterprises. Still, waste production increased from 526 million metric tons in 1985 to 618 million metric tons in 1992. Inexplicably, however, there was a huge drop in "industrial waste residue discharged": from 85 million metric tons in 1988 to 26 million metric tons in 1992.

I cannot think of any solid waste stream whose reduction would have resulted in such a steep decline. Waste dumping of two major kinds of solids that cannot be readily recycled had to increase. First, higher mineral extraction had to result in a higher mass of mining wastes that have virtually no subsequent use. Second, the fast growth of coal-fired electricity generation had to produce more captured fly ash, whose use in building materials and as a fertilizer could not have increased so dramatically in just four years.

Moreover, even this puzzling drop is not enough to explain a substantial decline in the officially claimed total mass of accumulated solid waste—from a peak of 6.75 billion metric tons

*A poisonous compound used chiefly as an insecticide.

in 1989 to 5.9 billion metric tons in 1992. I have no explanation for how the Chinese eliminated nearly 1 billion metric tons of accumulated solid waste in three years. A minimum cost estimate can be made by assuming 6 billion metric tons of accumulated wastes, with an average density of 1.5 metric tons per cubic meter and a depth of at least 2 meters. These wastes would occupy some 200,000 hectares of land and, even with just average to slightly above-average crop yields, would represent a loss of RMB 700 million to RMB 900 million.

Rising urbanization had more than doubled the nationwide total of collected garbage, from about 31 million metric tons in 1980 to more than 71 million metric tons in 1991, yet the daily mean for China's large cities has grown only marginally during the decade to about 1.2 kilograms per capita in the early 1990s. Although this is very close to the annual mean of 1.3 kilograms per capita for members of the Organization for Economic Cooperation and Development (OECD),* and higher than the Japanese (1.1 kilogram) and German (0.9 kilogram) means, the composition of Chinese urban waste is very different.[62] In mass terms, most of the Chinese waste in northern cities is ash from burning coal, and most of the rest is kitchen waste. As residents in large cities use less coal, however, the share of ash is declining, whereas the proportions of packaging materials, plastics and of such toxic materials as solvents, paints, and pesticides are increasing.

It is certain that China must have a major problem with radioactive pollution in and around its nuclear production and testing facilities

Regardless of the actual make-up of China's household waste, its mass is dwarfed in every large Chinese city by industrial releases. In Shanghai these wastes, originating in more than 13,000 factories, totalled 10.55 million metric tons in 1989, nearly twice the 1980 total and four times the mass of household waste.[63] Although about one-fifth of this industrial waste was toxic, all of it was simply taken by barges to nearby landfills. Uncontrolled runoff and noxious emissions from these landfills have been affecting people for up to 5 kilometers from the two major sites. Given the high settlement density in the municipality's rural areas, about 120,000 villagers live within that radius. Without similar figures for all major Chinese cities, and without any detailed information on the composition of industrial solid waste, it is impossible to offer any nationwide estimate. The only published total of the annual costs of China's solid waste pollution is an unexplained estimate by Qu Geping and Li Jinchang of RMB 7.95 billion in 1986.[64]

Given the extent of soil contamination around the U.S. and Russian nuclear weapon-making sites, it is certain that China must have also a major problem with radioactive pollution in and around its nuclear production and testing facilities, and that the costs of managing this pollution may eventually far surpass those of disposing of ordinary industrial and urban solid waste. Unlike in the U.S. and the Russian case, though, there is no quantitative information in this respect.

Consequently, I will use Qu and Li's estimates of solid waste disposal

*In 1993 the OECD had 24 member countries: Australia, Austria, Belgium, Canada, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Japan, Luxembourg, the Netherlands, New Zealand, Norway, Portugal, Spain, Sweden, Switzerland, Turkey, the United Kingdom, and the United States. Values for Mexico and the Czech Republic, which became OECD members in 1994 and 1995, respectively, are not reflected in this figure.

costs[9] reduced by the cost of lost crop harvests (RMB 700 million to RMB 900 million) and adjusted for the year 1990; this procedure yields between RMB 9 billion and RMB 10.5 billion. Costs of radioactive wastes must be included among the missing entries.

CHINA'S ENVIRONMENTAL DEGRADATION

Pre-modern China was characterized by extensive conversion of natural ecosystems to crop fields. This ancient trend intensified during the past two generations, resulting in accelerated loss of farmland, increased soil erosion, and notable declines in the quality of cultivated soils. Other adverse effects of undesirable ecosystemic change are degradation of grasslands and increasing shortages of water.

Degradation of Farmlands

An often noted fact about China is that the country has to feed approximately one-fifth of the world's population from only about one-fifteenth (6.7 percent) of the earth's arable land. Given the uncertainties about the total availability of farmland both in China and worldwide, however, the latter share may be as low as 6 percent and as high as 8 percent. In any case, what matters is the large disparity between the two numbers. The

China has to feed approximately one-fifth of the world's population from only about one-fifteenth of the earth's arable land—these natural limitations have been aggravated by unusually high farmland losses and the declining quality of farm soils. (Shown: Harvesting wheat in Sichuan Province.)

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Few environmental changes have been as critical in affecting China's well-being as the combination of quantitative and qualitative farmland decline

pressure generated by this comparison is increased by three additional factors: (1) China's capacity for expanding farmland is very limited, (2) only about one-third of the country's farm soils are highly productive, and (3) at least one-tenth of the cropped area is affected annually by either droughts or floods.

Regrettably, these natural limitations have been considerably aggravated by unusually high farmland losses and the declining quality of farm soils. Few environmental changes have been as critical in affecting China's well-being as this combination of quantitative and qualitative farmland decline. Although these losses have been compensated by more intensive cropping and by steadily rising yields, such measures have clear biophysical limits: they take China's agroecosystem further away from sustainable practices and into a greater dependence on synthetic chemical inputs subsidized by higher conversions of fossil fuels.

Loss of Arable Land Incomplete official figures on arable land in China show an increase from 97.881 million hectares in 1949 to a peak of 111.830 million hectares in 1957. The only available figure for the next decade is 103.590 million hectares for 1965, and totals for the 1970s trace a slight decline from 101.1 million hectares in 1970 to 99.5 million hectares in 1979; by 1988 the total slipped to less than 96 million hectares. Combined with steady increases in population, these values imply a substantial decline in average per capita availability of farmland, from about 0.18 hectares in 1949 to 0.08 hectares in 1992 (Table 4). Per capita rates are now below 1 *mu* (that is, less than 667 square meters) in one-third of all provinces.

Official figures clearly underestimate, however, the actual extent of China's crop cultivation. The first generalized mapping of China's land use showed 139.3 million hectares of cultivated land in 1980, nearly 40 percent more than that year's official figure. Estimates as high as 150 million hectares were offered on the basis of LANDSAT images, and detailed sample surveys of the late 1980s came up with the most likely range of 133 million to 140 million hectares. Thus, whereas the official figures underestimate the farmland total, generalized land-use mapping and satellite surveys tend to overestimate it.

The best indication of the real extent of China's arable land comes from detailed county-wide sample surveys begun during the late 1980s, which came up with a likely range of 133 million to 140 million hectares.[66] Provincial differences are considerable, with the poorest areas reporting less than a third of actually farmed land. An unofficial nationwide total mentioned in recent Chinese reports is about 139 million hectares, whereas the Land Management Bureau used 122.9 million hectares for the year 1994. Taking a middle value of about 130 million hectares would prorate to almost 1,100 square meters (0.11 hectares) per capita, which is more than twice the rates for South Korea and Taiwan and three times the Japanese mean.[67]

Whatever the country's real farmland total, Chinese experts feel that the overall extent of inaccuracy in reporting cultivated land has not changed significantly during the last 30 years, and hence there can be no doubt about substantial, and continuing, losses of cropland. I believe that making the best possible assessment of these losses is much more profitable

KAZAKHSTAN
UZB
KYRGYZSTAN
Ürümqi
Xinjiang
TAJIKI-
STAN
AFG
PAKISTAN
Qinghai
Yangzi River
Xizang
NEPAL
BHUTAN
INDIA
BANGLADESH
MYANMAR
Bay
of
Bengal
66°
70°
74°
78°
82°
86°
90°
94°
54° N
50°
66° E
46°
42°
70° E
38°
34°
74° E
30°
26°
22°
78° E
18° N
82°
86°
90°
94°
98°
18° N

RUSSIA
MONGOLIA
Hulun Buir grasslands
Da Hinggan Mountains
Heilongjiang
Songhua River
Sanjiang Plain
Mudanjiang
Changchun
Jilin
Changbaishen
Nei Mongol
Shenyang
Liaoning
Hebei
NORTH KOREA
Sea of Japan
Hohhot
Yellow River
Beijing
Tianjin
Bo Hai Bay
Gansu
Yinchuan
Taiyuan
Shijazhuang
SOUTH KOREA
Shandong
Yellow Sea
Xining
Ningxia
Loess Area
Shanxi
Jinan
Linfen
Lanzhou
JAPAN
Henan
Jiangsu
Xi'an
Anhui
Shaanxi
Danjiangkou
Hefei
Shanghai
Hangzhou Bay
Yangzi Basin
Sichuan
Zhejiang
East China Sea
Chongqing
Dongtinghu
Xinjiang
Nanchang
Changsha
Hunan
Jiangxi
Guizhou
Fujian
Guiyang
Kunming
TAIWAN
Liuzhou
Guangdong
Yunnan
Zhu (Pearl) River
Guangxi
Hong Kong
VIETNAM
South China Sea
Hainan
PHILIPPINES
LAOS
98°
102°E
106°
110°
114°
118°
122°
126°
130°
134°
138°
142°
54° N
50°
142° E
46°
42°
138° E
38°
34°
134° E
30°
26°
22°
130° E
18° N

China's farmland decline stems from a combination of population and economic growth and degradative processes accelerated or initiated by improper land management

than trying to pinpoint the total number of hectares of farmland.

China's continuing farmland decline stems from a combination of population growth and economic modernization (industrial, urban, and residential expansion; extension of transportation links; construction of irrigation and power generation reservoirs) and degradative processes (heavy erosion, desertification, salinization, alkalization) frequently accelerated or initiated by improper land management. The history of these losses is marked by fluctuating trends in economic growth and land use.

Cumulative totals published in China since 1978 generally agree on a staggering gross loss of almost 30 million hectares during the 20 years between 1957 and 1977. Since 1978, farmland losses have been dominated by the demands of economic modernization, but during the initial years of reforms a substantial portion of the loss also resulted from the restoration of wetlands, grasslands, or slopelands converted into farmland during the two decades of Maoist campaigns.

Official totals published by the State Land Management Bureau put the average annual farmland loss at 492,000 hectares between 1980 and 1985, for a total of 2.45 million hectares. A peak loss of 1 million hectares was reached in 1985. This staggering total reflects above all the frenzied pace of rural house building by newly private farmers: between 1979 and 1986, 6.2 billion square meters of new housing were built in the Chinese countryside. In 1986 the loss decreased to 640,000 hectares, due mostly to the return of farmland to pastures, fish ponds, and orchards.

In 1987, the State Land Management Bureau introduced new regulations for the use of farmland for nonagricul-tural construction, permitting nationwide conversion of no more than 200,000 hectares for all construction projects, including just

Table 4. Total and per capita availability of China's farmland and reported farmland losses, 1949–1992

Year	Total (millions of hectares)	Per capita (hectares)	Gross farmland loss (hectares)
1949	97.88	0.180	
1957	111.83	0.173	*
1965	103.59	0.143	
1970	101.10	0.122	
1979	99.50	0.102	
1985	97.60	0.092	1,000,000
1986	96.85	0.090	640,000
1987	95.89	0.088	470,000
1988	95.72	0.086	510,000
1989	95.65	0.085	198,000
1990	95.67	0.084	733,000
1991	95.65	0.083	580,000
1992	95.60	0.082	243,000
1993	95.50	0.081	620,000

* The average loss for 1957–86 was 526,000 hectares per year.

Sources: Farmland totals are taken from various issues of *China Statistical Yearbook* (State Statistical Bureau) as are the population totals used to calculate the per capita values. Farmland losses come from statistics released by the Land Management Bureau and reported regularly by the Chinese media.

over 60,000 hectares for peasant housing. Steady declines in nationwide farmland loss followed.

By 1989 the Bureau felt that the situation was again under control, as the annual loss was reduced to just 198,000 hectares and the cultivated area actually increased in six provinces.[68] Ultimately, however, the increased pace of economic expansion, especially the virtually uncontrolled multiplication of rural industries and establishment of special industrial and processing zones, led to a renewed round of farmland losses. The annual mean for the first four years of the 1990s was almost 550,000 hectares. Predictably, this brought a new wave of decrees aimed, again, at reversing this worrisome trend.

An appreciation of these fluctuations is essential for any realistic evaluation of the long-term costs of China's farmland losses: taking a single-year value would lead to great distortions. Moreover, we should also look ahead to assess the most likely trend for the future, as the very low net rates of the most recent past may be as transitory as the unprecedented losses of the mid-1980s.

The cumulative loss of about 40 million hectares since the late 1950s is the equivalent of a loss in food production capacity for at least 350 million people

Unfortunately—given the continuing pressures of increasing population, rapid industrialization, and extension of transportation links—no radical long-term changes in China's rate of farmland decline seem likely. Moreover, the continuing losses will inevitably include some of the best-yielding land. For example, during the early 1990s thousands of newly established manufacturing zones have taken more than 80 percent of their land from intensively cultivated fields near towns and cities.

Staying below the State Management Bureau's target of about 200,000 hectares per year would remove close to 2 million hectares of farmland during the 1990s, but my disaggregated estimates show that actual losses could be at least 300,000 hectares per year and possibly up to twice as high.[69]

Besides representative annual rates we should have at least a rough breakdown of losses by region and/or soil quality to apply more specific values of lost production. I do not know of any such listings, but acceptable approximations can be based on totals of provincial farmland losses published since the mid-1980s. These figures indicate that the largest declines have been in the North and Northwest (in areas producing either a single crop per year or with multicropping ratios of no higher than 1.5), largely due to the reconversion of plowed-up pastures to grazing and the return of many wet fields to use as fish ponds. In terms of soil quality, a conservative assumption would be that at least one-third of all recently lost farmland was in the highest yield category, including most of the extensive suburban land losses in fertile valleys.

I calculate the economic costs of China's farmland loss by using the minimum annual loss of 200,000 hectares and the maximum long-term mean of 500,000 hectares (with the multicropping ratio of this land being no higher than the national average of about 1.5, this loss would represent an annual decline of 300,000–750,000 hectares of sown farmland). With an average value of annual crop production at RMB 3,250 per hectare, this would translate to between RMB 600 million and RMB 1,600 million, with a mean at RMB 1.1 billion.

Paddy fields account for at least one-fifth of total land loss, that is, for 40,000–100,000 hectares per year. Assuming that their ecosystemic

By the year 2000 Bangladesh and Egypt will be the only two populous nations with less arable land per capita than China

services are worth at least three times* the value of their annual production (an average of RMB 12,000 per hectare), then at least RMB 480 million and up to RMB 1.2 billion (mean of RMB 840 million) should be added to the cost of farmland losses. If the ecosystemic service value of dry fields is set no higher than the value of their crop production, the total economic cost of annual farmland loss should be increased by another RMB 0.52 billion to RMB 1.3 billion (mean of RMB 910 million), for a total of RMB 1 billion to RMB 2.5 billion.

The human dimensions of China's declining farmland area are best illustrated by translating the losses into annual food production equivalents or by comparing them with foreign farmland totals. The cumulative loss of about 40 million hectares since the late 1950s is the equivalent of a loss in food production capacity for at least 350 million people. The mean annual loss of more than 400,000 hectares during the 1980s was equal to a loss in food production for about five million people every year. Furthermore, losing 40 million hectares of farmland has been equal to taking away a bit more than all the fields in Argentina. Similarly, even if the losses could be kept to 200,000 to 250,000 hectares per year, in just a decade this would add up to all of the arable land in Egypt. Regardless of the prevailing rate of future losses, by the year 2000 Bangladesh and Egypt will be the only two populous nations with less arable land per capita than China. To offset these losses Chinese farming had to become much more intensive, and the country has emerged as the world's largest producer and consumer of synthetic fertilizers. Even so, there are many questions about its future capacity to feed itself.[70]

Besides losing farmland, the Chinese have also been continually creating it by conversion of grasslands, slopelands, and wetlands. During the 1950s these gains greatly surpassed the losses, but net losses have been the norm since the mid-1960s. Although the total of potentially reclaimable land is put as high as 30–35 million hectares, it is now generally accepted that only a small part, no more than about 10 million hectares, of the total is actually convertible to farmland at an acceptable cost. This land is concentrated in Heilongjiang's Sanjiang Plain, in the eastern part of the Hulun Buir grassland of Nei Monggol, in northwestern Xinjiang, and on the seacoasts of Jiangsu, Fujian, and Guangdong. Regardless of the location, reclamation costs are high. In the ideal case, the value of the potential crop production from lost fields would have to be compared with the cost of reclaiming new fields and with their potential output to establish the net effect of China's farmland changes.

Chinese agriculture is facing the challenge not only of decreasing farmland availability but also of declining soil quality. The two most important reasons for this change have been the spread and intensification of soil erosion and an unusually rapid decline in both the extent and the intensity of traditional organic recycling. The first phenomenon is an unfortunate worsening of a degradative process whose effects have been regionally severe for centuries, but the second one represents a relatively abrupt change in

* The multiplier is based on a Japanese study of the ecosystemic worth of wet fields (Yoichi 1992).

one of the key defining practices of Chinese agriculture.

Soil Erosion The extent of all lands affected by soil erosion was estimated at 1.53 million square kilometers in the early 1950s. A combination of satellite surveys and ground observations started in 1984 showed that, by 1992, 3.67 million square kilometers, or slightly more than one-third of China's territory, was affected in different degrees by soil erosion. The impact was increased by water erosion on 1.794 million square kilometers and wind erosion on 1.876 million square kilometers.[71]

A nationwide survey of nearly 45 million hectares (or almost half of China's farmland) in 901 counties discovered various degrees of excessive soil erosion on 31 percent of croplands. This means that about 30 million hectares of Chinese fields are affected, and, although I have not seen any detailed breakdown by erosion categories, some regional rates are likely very high. Indeed, the erosion rates on the Loess Plateau are the highest in the world: the annual soil loss rates in an area half the size of France have reached 300 metric tons per hectare, or the equivalent of 2 centimeters of topsoil denuded every year.[72] Very high rates have recently been reported from other provinces as well. In Heilongjiang, where excessive soil erosion now affects more than four-fifths of all fields, the annual denudation rates are as high as 0.4 centimeters to 0.7 centimeters. Similarly, by the late 1980s in Sichuan (China's most populous province with more than 110 million people and less than 600 square meters of arable land per capita), 44 percent of fields were eroding beyond the sustainable level (a fourfold increase compared to the early 1950s), and 2 million hectares of cultivated slopeland had annual erosion losses averaging 110 metric tons per hectare.[73]

These erosion rates are stunningly high. For comparison, the second round of the world's most detailed erosion survey showed that U.S. water erosion rates in 1987 averaged just over 9 metric tons per hectare and wind erosion rates amounted to more than 7 metric tons per hectare, for a total of approximately 17 metric tons per hectare on 170 million hectares of cropland.[74] These average soil erosion rates are higher than the maximum erosion rate compatible with sustainable cropping on U.S. soils (11 metric tons per hectare). Without fertilizer applications, this disparity would lead to steadily declining yields, and, if continued for several hundreds of years, it could prevent cropping on some soils due to inadequate rooting depth. But the situation is far more serious in China.

Given the quality and distribution of Chinese soils and the prevailing cropping patterns (lowland paddy fields have mostly negligible erosion rates), a fairly conservative assumption is that about one-third of China's farmlands have very low erosion rates (averaging 5 metric tons per hectare per year), about two-fifths have tolerable rates (averaging 15 metric tons per hectare per year), and the rest have excessive rates (divided between severe, averaging 50 metric tons per hectare per year, and extreme, averaging 100 metric tons per hectare per year). The weighted nationwide mean of China's farmland erosion would then most likely be around 30 metric tons per hectare; rates of 20 metric tons and 40 metric tons per hectare are, respectively, the most plausible minimum and maximum levels (Table 5).

Using the official figure of about 95 million hectares, the three weighted means would translate to total annual losses of roughly 2 billion, 3 billion, and 4 billion metric tons of topsoil; using a higher, and likely a more realistic estimate of 130 million hectares, the totals would increase to 2.6 billion, 3.9 billion, and 5.2 billion metric tons. The lowest value of the latter range is close to the U.S. total (2.8 billion metric tons in 1987), but China has only about half as much arable land. These ranges should be also compared with a figure repeatedly mentioned in recent Chinese reports, i.e., 5 billion metric tons of topsoil lost by all of China's eroding soils. This loss is claimed to be the

Table 5. Weighted means of China's estimated farmland erosion

% of total farmland	Total erosion losses (metric tons per hectare)		
	Minimum	Mean	Maximum
30	3	5	7
40	10	15	20
15	30	50	70
15	80	100	120
Weighted means	20	30	40

Erosion rates in China are stunningly high

equivalent of all macronutrients (nitrogen, phosphorus, and potassium) applied in chemical fertilizers.

The economic costs of soil erosion include crop-yield losses directly attributable to the diminishing soil base; the value of lost nutrients in terms of equivalent amounts of synthetic fertilizers; lost irrigation capacity and lost electricity-generating capacity of reservoirs due to silting; additional expenses for cleaning silted water for industrial and urban uses; capital expenses to counteract increased silting of river beds, lakes, and reservoirs by dredging, raising levees, and building new water storage facilities; and damage done by increased frequency and extent of flooding.

Crop yields and nutrient losses

Erosion affects crop yields in a number of ways: it reduces soil's organic matter, fine clay content, and water-retention capacity; it removes plant nutrients; and it limits plant rooting depth.[75] Eventually, average crop yields start declining, but there is very little reliable evidence to quantify losses.[76] Even the richest countries have only rough estimates of total soil mass eroded,[77] and quantifications of actual nutrient losses are just informed guesses.

Although the nutrient losses may vary considerably even within a single field, the main complicating factor is the degree to which eroded soil merely displaces nutrients to another part of the field or to other fields downstream or downwind. In gently sloping croplands most of the eroded soil does not end up in waterways but rather on different patches of cultivated land.[78] Steeper slopes may, however, lose most of their eroded soil. Similarly, wind erosion may either translocate nutrients within or among fields or totally remove them from the affected area.

As a result, it is exceedingly difficult to estimate actual nutrient losses from cropfields. Still, according to one 1985 study, the effects on crop production costs for the United States are smaller than most soil conservation experts have long believed.[79] The authors of another study concluded that the continuation of typical erosion losses in the U.S. cornbelt would lower average grain yields by only about 4 percent in 100 years, with extremes ranging from 2 percent on gentle slopes to 18 percent on steeper fields.[80] Thus, it would be reasonable to assume negligible long-term effects in most of China's wet fields—i.e., no more than a 5 percent yield reduction per century on fields with tolerable erosion rates—but, given the unusually high erosion rates on 30 percent of China's fields, at least a 25 percent yield loss on the worst affected farmland. These assumptions yield a weighted mean of 10 percent per century, or 0.1 percent per year. Yield declines of 5 to 15 percent per century would imply annual harvest losses of 2.6 to 7.9 (mean of 4.9) kilograms per hectare. With about 130 million hectares of farmland, an average yield close to 4 metric tons per hectare, and a crop production value of RMB 3,300 per hectare, approximate total annual costs would be between RMB 270 million and RMB 830 million.

These estimates, although high, still greatly undervalue the long-term ecosystemic impact of soil erosion: if the eroded macro- and micronutrients had remained in the soil their gradual incorporation into new crops and their recycling in crop residues and manures would have helped to produce higher harvests for many years. Consequently, it is more revealing to

approximate the substitute cost of annually lost nutrients.

As already explained, soil concentrations of nitrogen and phosphorus, the two principal plant macronutrients, vary widely. Therefore, I will use a fairly conservative range of assumptions based on the best available surveys of various soils.[81] Assuming nitrogen contents of between 0.125 percent and 0.175 percent (mean value of 0.15 percent), corresponding to between 2.5 metric tons and 3.5 metric tons of nitrogen per hectare, and phosphorus concentrations of between 0.09 and 0.19 percent (mean value of 0.14 percent) results in average nutrient losses of 5.6 million to 18.5 million metric tons, with a mean of 11.4 million metric tons, from 130 million hectares of farmland. With synthetic fertilizer valued at RMB 750 per metric ton in 1990, China's agricultural soil erosion would lead annually to a nitrogen and phosphorus loss equivalent to RMB 4.2 billion to RMB 13.9 billion. Increasing these totals by 10 to 15 percent to account for the losses of potassium and a variety of soil micronutrients brings the total to approximately RMB 5 billion to RMB 15 billion, with a most likely annual value of RMB 10 billion.

This estimate can be compared with the total derived from the repeated Chinese claim that nutrients in 5 billion metric tons of annually eroded soil (including erosion from nonagricultural land) are equivalent to total fertilizer applications. With such applications at about 25 million metric tons in 1990 and with an average value of RMB 750 per metric ton of synthetic nutrients, that loss would amount to RMB 18.75 billion.

Four-fifths of all lakes in eastern Hubei have already disappeared due to silting

Effects of silting Silting is an environmental problems of enormous importance in China, especially in and downstream from the Loess region in the North, i.e., along the lower course of the Huang He in Henan and Shandong. There has been no major dredging along the Huang He's lower course, where the river flows for about 1,400 kilometers confined by dikes that are at least 3 to 5 meters, and up to 11 to 15 meters, above the surrounding countryside. Consequently, the annual flow into the river from the Loess Plateau has increased from about 1.3 billion metric tons of silt in the early 1950s to more than 1.6 billion metric tons, the riverbed build-up amounts to about 400 million metric tons per year, and the average river bed rise has been around 1 meter per decade. Heavy and increasing silting therefore keeps increasing the risks of catastrophic flooding of the North China plain. The latest estimates are that a break in a dike south of Jinan would flood up to 33,000 square kilometers, affect 18 million persons, and cause enormous disruption of key transportation links (cutting all north-south railways).

The higher risk of silting-induced flooding is not limited, however, to the Huang He basin. Because of extensive deforestation in the upper parts of the Yangzi basin, more than 40 percent of this huge watershed is now affected by soil erosion, compared to just 20 percent 40 years ago.[82] Between 2.2 billion and 2.4 billion metric tons of silt are now carried downstream from Sichuan every year, raising the riverbeds and lake levels in Hubei and Hunan. Four-fifths of all lakes in eastern Hubei have already disappeared. Likewise, in the Dongtinghu in northern Hunan, once China's largest freshwater lake, only one-quarter of the annual inflow of

Crippling floods in 1991 affected 80 percent of Anhui's 55 million persons, marooned about 9 million, and destroyed 1.5 million houses

160 million cubic meters of silt is discharged, and the deposits elevate the bottom of the lake by about 2.5 centimeters per year. Not surprisingly, many Chinese scientists see the silting of the central Yangzi lowlands as a major reason for the extensive damage done by recent floods.

No aggregate estimate about the silting of irrigation canals is available, but it is claimed that waterborne silt has been responsible for displacing more than 1 billion cubic meters of reservoir storage capacity each year.[83] This is equal to about 0.2 percent of China's total irrigation reservoir capacity (466 billion cubic meters in 1990). Replacing this lost volume by new reservoirs costs between RMB 0.5 and RMB 0.7 per cubic meter,[84] or RMB 500 million to RMB 700 million a year. If we assume that the yields of irrigated crops will be reduced by the same percentage as reservoir capacity (0.2 percent), the annual cost of the forfeited harvest (with an average production value of at least RMB 4,000 for each of the roughly 50 million hectares of irrigated land) would be about RMB 400 million. An alternative estimate is to assume, based on well-known water requirements of major grain crops, that 1 billion cubic meters of water could produce an additional 1 million metric tons of rice and wheat worth about RMB 600 million.

A similar estimate can be done for the annual cost of reduced hydroelectric generation. This effect has reached locally shocking proportions. For example, Danjiangkou, China's most voluminous reservoir on the Han Shui in Hubei, lost one-seventh of its capacity in just a decade. The best nationwide estimate is that the excessive accumulation of silt has eliminated the equivalent of one-fourth of the reservoir capacity built between 1960 and 1989, resulting in a total direct cost of RMB(1989) 20 billion.[85]

In the early 1980s, researchers claimed that the country's 11 largest reservoirs were losing 2.3 percent of their total storage capacity of 37 billion cubic meters annually.[86] As these plants were designed to generate about 40 terawatt* hours of electricity annually the loss of 2.5 percent would be equivalent to forfeiting 1 terawatt hour per year. At roughly RMB 0.2 to RMB 0.25 per kilowatt hour, this would represent a total cost of about RMB 200 million to RMB 250 million. Given an average load factor of about 50 percent, generation of 40 terawatt hours of electricity requires installed capacity of about nine gigawatts.† As the capital cost of building China's hydroelectric stations (including transmission) is RMB 4,000 to RMB 5,000 per kilowatt, replacing this lost generation capacity would require an investment of about RMB 36 billion to RMB 45 billion, or about RMB 1.2 billion to RMB 1.5 billion prorated over 30 years. The combined cost of lost generation and capacity replacement would then be about RMB 1.4 billion to RMB 1.8 billion per year.

Expenses for clearing silt Clearing away just half of the 1 billion cubic meters of silt added annually to irrigation canals and ponds would take at least 250 million person-days of labor. With average daily rural wages of between RMB 5 and RMB 7, this task would cost RMB 1.3 billion to RMB

* A terawatt is equal to a trillion watts.

†A gigawatt is equal to a billion watts.

1.8 billion. If about 40 billion cubic meters of water (about one-third of that used by industries and households) needed additional cleaning, adding just 2 percent to the cost of supplied water, the annual expense would total (at an average cost of water at RMB 0.5 to RMB 0.6 per metric ton) RMB 400 million to RMB 500 million.

Flood damage A long-term average of flooding damage must be used to assess the impact of riverbed and lake silting. Using an annual mean of 5.5 million hectares of farmland disastrously affected by flooding (the average for the 1980s) and assuming that increased silting is responsible for 10 to 30 percent (average 20 percent) of this damage (an estimate in line with increased rates of silting compared to the 1950s), the annual value of crop production would be reduced by at least 30 percent (China's definition of disastrous effect) on 550,000 hectares to 1.65 million hectares (average of 1.1 million). Even if the reduced output averages no more than 40 percent, the annual cost (given an annual gross output value of RMB 3,250 per hectare) would be between RMB 700 million and RMB 2.15 billion (mean of RMB 1.4 billion). Property damage caused by flooding is much more variable. Recent Chinese estimates range from just a few billion RMB to tens of billions RMB for the record 1991 floods that were especially crippling in Anhui and Sichuan. They affected 80 percent of Anhui's 55 million persons, marooned about 9 million, and destroyed 1.5 million houses.[87] Assuming the average long-term property damage from flooding at just RMB 10 billion per year (range of RMB 5 billion to RMB 15 billion) and attributing about 20 percent of it to the increased rate of silting would add between RMB 1 billion and RMB 3 billion (mean of RMB 2 billion) to the damage done annually to crops.

Other Farmland Degradations The recent national soil survey found that only about 15 percent of China's farmlands have no unfavorable production factors. Besides erosion and declining organic matter, about 5 percent of agricultural soils are affected by desertification* and 9 percent by waterlogging; about half of the latter area (approximately 4.3 million hectares) consists of insufficiently drained paddies. Salinization—arising from inadequate drainage and improper irrigation—has lowered crop yields on about 7 million hectares. The use of untreated urban sewage has also seriously damaged about 2.5 million hectares of suburban cropland.

Loss of organic matter The loss of organic matter has been noted in many farmlands around the world. In most of China, however, traditionally vigorous organic recycling has until recently kept this vital soil property from deterioration. The three key reasons for an abrupt shift in this long-standing practice have been (1) the increased availability of synthetic fertilizers (China has been the world's largest consumer of nitrogenous compounds since the early 1980s and the largest producer since the late 1980s); (2) the pressures of privatized farming favoring higher yields of monocropped cereals; and (3) the construction of modern sewage treatment facilities in large cities.

A national soil survey conducted in about 1,400 counties revealed that 11 percent of China's farmlands have less than 0.6 percent of organic matter in their soils and that the average nationwide value has dropped below 1.5 percent.[88] The decline of organic matter in long-cultivated soils can be readily traced to the lower rates of organic recycling documented by many local and provincial reports. In Heilongjiang in the early 1990s, half of all farmers applied no manure; in Anhui only 5 percent of urban wastes have been recycled since the late 1980s; and in Jiangxi the use of organic fertilizers decreased by more than half compared to traditional practices.

The most important consequences of the decline in organic matter are hardening of soils, higher runoffs, and, most important, a reduction in the number of soil invertebrates, especially earthworms. Earthworms are the principal soil tillers and irreplaceable agents of soil humification, but they can provide these irreplaceable ecosystemic services only in soils rich in organic wastes.[89]

Productivity losses from contamination, pollution, and residues By the late 1980s, about 13 million hectares of China's cropland were contaminated by the residues of persistent pesticides, and almost seven million hectares were polluted by a variety of industrial wastes, ranging from mining residues to untreated water discharges from small industries. The Ministry of Agriculture has estimated that untreated water discharges alone were responsible for annual harvest losses equivalent to at least five million metric tons of grain.[90] Unfortunately, the continuing indiscriminate

*The rapid loss of plant life and topsoil.

expansion of rural industries will only increase this form of cropland degradation.

Mining has disturbed about 2 million hectares of land, and its claims are increasing by at least 20,000 hectares per year.[91] At least 20 to 30 percent of this is arable land with reclamation costs at least RMB 4,000 to RMB 8,000 per hectare, and for some sites up to RMB 20,000 to RMB 35,000 per hectare. Average harvests from this restored land are, however, worth only RMB 700 per year. The annual cost of reclaiming 20,000 hectares at RMB 5,000 to RMB 10,000 per hectare is RMB 100 million to RMB 200 million.

A new threat to the quality of China's arable land comes with the spreading use of plastic sheeting to conserve soil moisture and accelerate the ripening of crops. I have not come across any nationwide appraisals, but, by 1990 in Heilongjiang, more than 10,000 metric tons of torn plastic sheets became mixed with the soil on more than 100,000 hectares of farmland. Their presence hinders the flow of water, interferes with root growth, and reduces grain yields by up to 15 percent. Because the use of sheeting is now so widespread in China, a conservative estimate is that at least 1 million hectares of farmland are affected by the presence of torn plastic and that yields in those fields are reduced by at least 5 percent.

Degradation of Chinese grasslands and wetlands has been rapidly transforming, often irreversibly, some of the country's most productive ecosystems

Cost estimates The cost estimates of these degradations can be divided into two categories. First are the widespread losses arising from declining soil organic matter, and second are the relatively limited, but in aggregate very important, other degradations.

The continuing long-term decline of soil organic matter has greater consequences for crop productivity than the loss of nutrients that are replaceable by synthetic fertilizers. A very conservative assumption would make it equal to yield declines arising from nutrient losses, i.e., to annual totals of RMB 180 million and RMB 570 million (mean of RMB 350 million); doubling of those totals would not be excessive.

The total area of farmland affected by desertification, waterlogging, salinization, alkalization, pesticide contamination, industrial pollution, and plastic residues amounts to about 50 million hectares. Average crop yield declines of 2 to 4 percent would translate to annual losses of RMB 3.25 billion to 6.5 billion (mean of RMB 4.9 billion).

It must be noted, however, that there may be some nontrivial overlaps in estimating costs of decreased harvest resulting from land degradation and water shortages and from air and water pollution, as well as difficulties with attribution within some loss categories (there are, for example, clear feedbacks among soil erosion, declining soil organic matter, and flood intensity).

Grasslands and Wetlands

Although it has attracted much less domestic and foreign attention than farmland losses or deforestation, degradation of Chinese grasslands and wetlands has been rapidly transforming, often irreversibly, some of the country's most productive ecosystems. Overgrazing and conversion of grasslands to croplands have contributed to increased soil erosion and desertification, and destruction of wetlands has increased the risk of flooding and accelerated the loss of biodiversity.

China's grasslands were originally

The most important ecosystemic consequence of grassland degradation and conversion into cropfields and construction sites is the substantial increase in erosion

among the most diverse in the world, containing more than 5,000 herbaceous species, including about 1,100 legumes.[92] Various sources put their total area in the late 1980s and early 1990s at between 280 million and 400 million hectares, but pastures actually supporting either large (cattle, horses, yaks) or small (sheep and goats) grazing animals total no more than 225 million hectares. Only about 30 million hectares of these pastures have grass yields of the 2 metric tons per hectare necessary to support large animals. On the other end of the productivity spectrum are arid grasslands yielding less than 400 kilograms per hectare and suitable only for marginal sheep grazing. Degraded grasslands covered close to 90 million hectares by 1990, and their area has been recently increasing by at least 1.3 million hectares annually.

Desertification, induced by overgrazing, has degraded 70 million hectares of pastures since the early 1950s, and conversion to farmland, although now much lower than during the peak rates of the 1970s, has been reducing China's grasslands by between 0.67 million and 1.3 million hectares per year. In Nei Monggol, China's principal cattle-grazing region, at least one-third of all grasslands are affected by desertification and deterioration caused by overgrazing. Qinghai's grasslands shrank by more than one-fifth (7 million hectares) by the late 1980s, and their yield has been further reduced by rats consuming annually more than 4 million metric tons of grass, the equivalent of forage for about 3 million sheep. Moreover, a recent gold rush has destroyed more than 200,000 hectares of the province's grasslands.

The extensive conversion of grasslands to cropfields and the overstocking of declining pastureland have led to an unsustainable increase in animal densities and common overgrazing. Nei Monggol averaged 0.24 sheep per hectare in the early 1950s, but the rate now is approaching one animal per hectare; Qinghai's sheep density more than doubled during the past 40 years. International comparisons highlight the inherently low productivity of Chinese grasslands. Their average carrying capacity is just 0.8 sheep per hectare of pasture, whereas the mean stocking rates are more than 30 in the former Soviet Union, almost 50 in the United States, and more than 110 in New Zealand. This low productivity reflects the naturally marginal environmental conditions of many Chinese grasslands (too arid, too cold), but its recent deterioration has been overwhelmingly the result human mismanagement.

Declining mutton and wool production have been the two most important direct economic consequences of grassland degradation. Mutton production in the late 1980s was about 20 percent lower than during the 1960s, an annual equivalent of at least 150,000 metric tons of meat representing a loss (at RMB 5 to RMB 7 per kilogram) of about RMB 750 million to RMB 1.05 billion. Because of declining domestic wool output China now has to import about 200,000 metric tons of wool annually at a cost of more than U.S.$1 billion. Straight conversion by use of the official exchange rate would make this equivalent to more than RMB 8 billion, but a more realistic conversion using a mixture of domestic prices for different grades of wool would be between RMB 2 billion and RMB 3 billion.

By far the most important ecosystemic consequence of grassland degra-

Overgrazing and conversion of grasslands to croplands have contributed to increased soil erosion and desertification.

STILL PHOTOS

dation and conversion into cropfields and construction sites is the substantial increase in erosion. Whereas in tact grassland soils erode mostly at rates below 5 metric tons per hectare, erosion from degraded sites can reach at least 10 to 20 metric tons per hectare. Erosion from arid fields and barren sites in northwestern China is at least 30 to 40 metric tons per hectare and often well over 80 metric tons per hectare.

Additional topsoil losses from 90 million hectares of degraded grasslands would thus amount (given an average of at least 15 metric tons per hectare) to about 1.4 billion metric tons. Another 100 million metric tons should be added for losses from about 1 million hectares of grassland converted each year. The total of 1.5 billion metric tons of additional topsoil loss would be equivalent to at least one-third, and more likely two-fifths, of erosion losses from China's cropfields. Even if its economic impact is prorated at just one-third to one-half the value estimated for the consequences of arable land erosion, the annual cost would come to between RMB 900 million and RMB 1.3 billion.

Although the effects of desertification—affecting large areas in all of China's northern border provinces as well as in Shanxi, Shaanxi, Ningxia and Gansu—are not limited to grasslands, most of this ecosystemic degradation does occur along the fluid boundary between deserts and grassy vegetation. The annual rate of this process, so very difficult to control, is now estimated at just over 210,000 hectares, almost 25 percent higher than a generation ago. The process lowers yields in both pastures and cropfields (these effects have been already accounted for) and also causes hardships for inhabitants in exposed settlements and for the maintenance of threatened transportation links. China's deputy minister of forestry put the annual rate at 230,000 hectares and the direct economic cost of progressing desertification at RMB(1993) 4.5 billion.[13] Because of the variety of effects, I have included the estimates of desertification costs

in appropriate categories dealing with soil erosion and farmland and grassland degradation.

The two most important ecosystemic services provided by wetlands are to reduce the effect of floods and to support high biodiversity. China's wetlands cover about 7 percent of the country's territory. Interior marshes total about 11 million hectares, and coastal wetlands and mudflats extend over more than 3 million hectares. Both kinds of ecosystems have been traditionally viewed as wasteland to be reclaimed.

The interior wetlands were badly affected by conversions to farmland during the 1960s and 1970s. One researcher estimated that 13,000 square kilometers of lake and wetland areas had disappeared in the lower Yangzi basin since 1954.[94] This would imply an annual conversion of about 35,000 hectares. Although such state-promoted mass campaigns ceased in the early 1980s, wetlands are still declining owing to a combination of new industrial development, transportation links, and irrigation schemes. Moreover, rapid losses of China's farmland during the 1980s have brought back the plans for massive reclamation of coastal wetlands. More than 2 million hectares of coastal marshes are slated to be converted into cropfields, but the high cost of such reclamation—at least RMB(1989) 14 billion—will stall its realization.[95]

The annual conversion of 20,000 to 40,000 hectares of wetlands whose ecosystemic services should be valued at least as much as those of paddy fields—i.e., RMB 12,000 per hectare, with the actual total certainly higher given the much higher water retention capacity and biodiversity—would yield an annual cost of about RMB 240 million to RMB 480 million.

Forests

After more than a decade of reports detailing the continuous decline of the country's forest resources came a surprising reversal. The results of the Third National Survey of Forest Resources conducted between 1984 and 1988 revealed that the annual increment of harvestable woody biomass had surpassed nationwide wood consumption, and the Fourth Survey, done between 1989 and 1993, showed that this annual surplus had grown to 80 million cubic meters. If true, China's forest resources would be expanding at an impressive rate. The following chronological appraisal shows, however, that such a reversal—suspect, but possibly correct in purely quantitative terms—signifies neither an encouraging ecosystemic trend nor a welcome new economic reality.

Deforestation and Afforestation In 1979 reports of extensive deforestation were among the first signs of China's worrisome environmental degradation. Subsequently, three factors rapidly increased China's demand for timber: record economic growth rates, the unprecedented pace of housing construction, and the fast expansion of coal mining. Between 1979 and 1986 timber production rose by more than 20 percent (from 54.4 million to 65 million cubic meters). At the same time, realistic appraisals of afforestation—the conversion of bare or cultivated land into forest—revealed the limited impact of previously extolled mass planting campaigns.

According to the First National Survey of Forest Resources, conducted between 1973 and 1976, fully stocked productive forests (that is, growth with canopies covering at least 30 percent of the ground) contained about 9.5 billion cubic meters of wood, and their annual wood increment was estimated at 220 million cubic meters.[96] Clearly, this inventory would have come up with very different totals if the official afforestation claims were even half true. Official statistics put China's 1949–79 timber harvests at 1.01 billion cubic meters, but the actual removal of woody phytomass was about five times larger. This is because the reported timber harvest represents only about two-fifths of the actually felled wood; and fuelwood, which has never appeared in official harvest statistics, accounts for about three-fifths of the total felled volume.[97] An average annual increment of at least 150 million cubic meters would have produced about 4.5 billion cubic meters, which means that, without any afforestation, China's forested area should have remained roughly stable. The increase to 122 million hectares from 83 million to 95 million hectares in 1949 implies afforestation of only 27 million to 39 million hectares, rather than the officially claimed 104 million hectares.

Revised Chinese afforestation estimates agree with this approximate assessment. Afforestation campaigns restored tree cover on 28 million to 30 million hectares of land during the years 1949–79, or on less than 30 percent of the area claimed by the past official planting statistics.[98] Two-thirds of these plantings were in timber stands, about 13 percent in bamboo groves, just over 6 percent in shelterbelts,* and a mere 2 percent in fuelwood lots (the remainder was for mixed use).

* Tree plantings designed to reduce wind speed near the ground and prevent excessive soil erosion.

Reports in 1979 of extensive deforestation were among the first signs of China's worrisome environmental degradation

During the 1980s the quality of afforestation improved significantly in most of the newly permitted private fuelwood lots, but the average success rates in state-sponsored plantings remained relatively low. Moreover, a survey by the Northwest Institute of Forestry in Xi'an indicated that false reporting, so common during the 1970s, had not ceased. Half of the reported national claims of the mid-1980s were found to be false, and the survival rate of planted trees was determined to be no higher than 40 percent.[99] Even the properly planted trees had great difficulty surviving the combined effects of prolonged droughts, pest infestations, and fires.

Pest problems in China's forests of the 1980s were particularly severe. The area of annual infestation was reported to be higher than the area of total afforestation, and the annual economic loss caused by insect pests was said to equal the state's total investment in forestry.[100] Total annual wood loss caused by pests was estimated at 11.5 million cubic meters. If only a quarter to a third of this total was the result of improper forest management, the annual timber loss would be RMB 1.9 billion to 2.5 billion. There was also considerable damage to shelterbelt trees. By 1988, about 4.7 million hectares of shelterbelts in northern provinces (i.e., almost half of all plantings) were seriously affected by pests, and about 10 million trees were destroyed.[101]

Another serious threat to China's tree plantings has been the inadequate prevention of forest fires and poor fire-fighting capabilities. These failings were most dramatically demonstrated by the huge Da Hinggan Mountains fire: between 6 May and 2 June 1987 it destroyed 1.01 million hectares of mostly mature, productive coniferous forest and also burned 855,000 cubic meters of stored timber.[102] In total, the northeastern forest experienced 4,900 fires between 1949 and 1989. The fires burned or damaged about 10 million hectares, or roughly eight times the region's newly afforested area.[103] The best nationwide estimate is that about one-third of successfully established new plantings were eventually damaged by fires. An annual loss of just 150,000 to 200,000 hectares of even lightly stocked forests (50 to 70 cubic meters per hectare) to forest fires would total RMB 5 billion to RMB 9 billion.

Thus, the combination of false reporting, early sapling mortality caused by poor planting and inadequate care, and pest and fire damage means that, of the 3–5 million hectares claimed as newly afforested every year during the late 1980s, at best 1.2–1.8 million hectares represent the real net gain. This estimate is confirmed by two contrasting sets of recent Chinese afforestation figures.

Totals provided by the Ministry of Forestry showed China's forest cover declining from 121.86 million hectares in the mid-1970s (based on the First National Survey) to 115.28 million hectares during 1977–81 (the term of the Second Survey), and then increasing to 124.65 million hectares for the period of the Third Survey (1984–88).[104] Plantations accounted for 19.4 percent of the total in the first period (23.7 million hectares), 24.2 percent in the second (27.8 million hectares), and 30.7 percent in the third (38.3 million hectares). These figures document a steady decline in China's mature forests and present afforestation gains averaging about 1.2 million hectares per year.

An official announcement claimed, however, that 15.78 million hectares were planted between 1986 and 1990, compared with 14.77 million hectares planted during the first half of the 1980s: the total prorates to just over 3 million hectares a year.[105] The latter figures clearly represent consecutive annual claims forwarded to the capital by lower layers of bureaucracy, whereas the Ministry's surveys come much closer to capturing the reality of long-term survival. The average survival rate of about 40 percent (1.2/3) is better than the 1949–79 record, but the real figure may still be lower. The same source put the total area of China's tree plantations at 30.7 million hectares in 1990, a figure 20 percent smaller than the 38.3 million-hectare total resulting from the second nationwide survey completed in 1988.

No one familiar with these discouraging trends—rising wood demand, continuing deforestation, and poor quality afforestation—was surprised when the results of the Third Nationwide Survey of Forest Resources, released in 1989, found a combination of declining forested area, diminishing growing stocks, and poor-quality timber. The area of state-owned forests shrank by almost 25 percent (12.85 million hectares) during the 1980s, with mature growth accounting for 60 percent (7.69 million hectares) of this large decline. In China's most important commercial timber base—in the provinces of Heilongjiang, Jilin, and Nei Monggol—the area of mature forests decreased by nearly 50 percent![106]

Wood shortages have already forced China to prohibit many uses of wood and to become a major timber importer

In December 1990 the Ministry of Forestry decided that, although the total forested area had increased substantially, wood consumption continued to surpass the growth rate and that, to remedy this imbalance, timber harvests should be limited during the next five years to a maximum of 243.6 million cubic meters per year.[107] Wood shortages had already forced China to prohibit many uses of wood and to become a major timber importer. Widely disregarded prohibitions forbade the use of wood for floors, stairs, windowsills, railway sleepers, cremation, and coffins, for example, and with the exception of 1985, the country has spent more than U.S.$1 billion per year every year since 1984, mainly for shipments of wood from Canada and United States.[108]

Gains or Losses? Such realities are not reversed in a year or two, but, by 1992, the Chinese media were claiming that afforestation had achieved a surplus of timber. The so-called Third Forest Census, which *China's Statistical Yearbook* and other Chinese sources claim was conducted between 1988 and 1991, put the total forested area at 128.63 million hectares (almost 12 percent higher than a decade before), the total growing stock (in all forests and woodlands with at least 30 percent canopy cover) at 10.868 billion cubic meters, and the growing stock in commercial forests at 9.31 billion cubic meters, valued at RMB(1990) 1.29 trillion.[109] Unfortunately, it is not clear if this study is different from the Fourth National Survey of Forest Resources done between 1989 and 1993, or if the two surveys overlap.

With the new annual increment estimated at 366 million cubic meters and the annual consumption at 327 million cubic meters, the census ended up with an annual surplus aver-

By the year 2000, almost 70 percent of China's state forestry bureaus will have no trees to fell

aging 39 million cubic meters of timber during 1989–91, the first such gain in many years.[110] A subsequent claim increased the consumption estimate to 344 million cubic meters, however, thus reducing the surplus to 22 million cubic meters. In December 1993 it was announced that total annual growth surpassed 400 million cubic meters, whereas consumption declined further to 320 million cubic meters.[111]

These figures represent a fundamental reversal in a single decade. Averages of the 1977–81 survey put wood harvests for all uses at 294 million cubic meters and annual increments at 275 million cubic meters, creating a yearly deficit of 19 million cubic meters, or about 7 percent above the theoretically sustainable cutting rate. Results from the Third Forest Census showed annual growth surpassing consumption by more than 6 percent of all harvests and a 1989–93 annual surplus equal to one-quarter of all tree felling (Table 6).

The total 1981–91 increase in annual growth would thus be approaching 50 percent, and China's 1993 wood harvest/growth ratio would have stood at 0.8 in 1993, just marginally worse than the ratios of such prodigious, and heavily forested, producers of wood as the United States or Finland, which were, respectively, 0.75 and 0.73 in 1990.[112] This comparison alone should alert us to the fact that the Chinese figures are not really what they seem to be. Even if we were to assume that most, or even all, of the 45 percent gain was real, however, its practical import appears in a different light once one realizes the changing composition of China's forest biomass and the spatial distribution of its harvests.

Because of the rising share of new plantings in the total coverage, 82 percent of China's timberland in 1990 consisted of young or middle-aged stands. Timber reserves available for commercial harvesting declined by 2.308 billion cubic meters during the 1980s, with mature stands decreasing by 170 million cubic meters annually; the growing stock ready for harvesting in mature forests amounted to less than 1.5 billion cubic meters. Reserves approaching maturity are projected to decline from about 2.6 billion cubic meters in the late 1980s to just 1.25 billion cubic meters by the end of the century. Reserves of mature timber available for harvesting fell sharply in Heilongjiang and Nei Monggol, the country's leading production areas.[113] In 1949 they stood at about 2 billion cubic meters of timber in some 12 million hectares of forest but by 1993 were down to just 470 million cubic meters in 5 million hectares.

Many new plantings—e.g., the relatively large southern pine plantations or small private lots of fast-growing fuelwood species—may be doing well, with their growth reflected by the rising volume of the standing stock, but the state record in replanting principal commercial logging areas has been poor. This neglect is creating a major resource crisis: of the 131 state forestry bureaus in the most important timber production zones, 25 had exhausted their reserves by 1990. Forty of the bureaus can harvest up to the year 2000, but, by then, almost 70 percent of China's state forestry bureaus will have no trees to fell.[114] Among the collectively run forest districts, 250 counties were suppliers of commercial timber in the 1950s, but only about 100 were delivering by 1990.

From a large-scale ecosystemic

Table 6. Areas, growth, and harvests of China's forests

Period	Total area (millions of hectares)	Annual growth	Annual harvest	Balance
		(millions of cubic meters)		
1973–76	121.86	220	196	+ 4
1977–81	115.28	275	294	– 19
1984–88	124.65	366	344	+ 22
1989–93	128.63	400	320	+ 80

Source: Compiled from surveys cited in the text and Ministry of Forestry (1994).

point of view it makes a great difference if trees are disappearing in steeply sloping upper basins of major rivers and are newly planted on oddland in alluvial farming areas. Reports by the Ministry of Water Resources acknowledged that the deforestation in the upper Yangzi basin has already done more damage than soil erosion control can restore.[115] By 1988 the forest cover in Sichuan, China's most populous province, was down to 12.6 percent, from 19 percent in the early 1950s.[116]

Reports published during 1989 and 1990 showed that the prospects are made even worse by the very low productivity of new plantings.[117] The official figure for the average growing stock in forest plantings—28.27 cubic meters per hectare—documents that the new plantings, whose growing stock may now be yielding a statistical nationwide wood surplus, offer little hope for replacing the felled mature forests for many decades. Growing stock in these forests would be at least 70–80 cubic meters per hectare (Heilongjiang's mean in 1993 was 90 cubic meters per hectare, down from about 140 cubic meters per hectare in the early 1950s). The inevitable conclusion is that, even if real, the recent quantitative growth of Chinese forests hides a major qualitative decline.

There are also good reasons to question the accuracy of figures indicating a small but steady decline in total wood harvests. During the period 1984–88, commercial timber accounted for less than one-fifth of the total harvest of nearly 350 million cubic meters: about 150 million cubic meters of woody phytomass were cut to supply approximately 60 million cubic meters of logs for sawnwood and pulpwood. The difference—amounting to approximately 60 percent of the total commercially felled volume—was wasted. The remaining volume of around 200 million cubic meters, or nearly three-fifth of all wood harvests, became fuelwood for China's energy-deficient countryside.

Other Chinese sources indicate that fuelwood consumption may be larger still. The Ministry of Energy put the total combustion of woody biomass (coming from any accessible tree and shrub parts, including lopped-off branches, stripped bark, pruning twigs, roots, and stumps) at about 230 million metric tons in 1987.[118] With an average of between 600 and 700 kilograms per cubic meter, this would translate to 300–350 million cubic meters of wood equivalent. A nationwide survey conducted in 1986 and 1987 put the total annual fuelwood consumption at 355 million cubic meters.[119]

Although the post-1980 expansion of small coal mines greatly increased rural fuel supplies in a number of coal-rich provinces, and although the large-scale adoption of better stoves resulted in some appreciable wood savings in many areas,[120] it is most unlikely that the total demand for fuelwood has been declining. China's fuelwood use prorates to about 3 kilograms of fuel per day per rural household, much less than the minimum needed for cooking three meals a day: every year for several months more than 300 million people have difficulty finding enough fuel for just cooking. In this situation it is unrealistic to expect any substantial short-term wood savings.

Moreover, it is quite likely that massive increases in wood demand for thousands of newly opened brick kilns alone have more than compensated for any reductions resulting from more coal burning by households. This demand will only grow: by the year 2000 these kilns—and, to a lesser extent, other wood-burning township enterprises—may consume more than 100 million cubic meters of wood per year, the equivalent of about one-third the total officially claimed harvest in the early 1990s. These surveys and calculations support another published comparison that concluded that the nationwide annual wood growth of 300 million cubic meters is surpassed by 400 million cubic meters of consumption.[121]

Growing demand will also be seen in just about every urban-industrial wood-consuming sector. Current Chinese annual consumption of commercial timber is approximately 0.05 cubic meters per capita, which is less than a tenth the rate in typical industrialized countries. Wood consumption in large state-owned coal mines

The overcutting of China's mature forests is equivalent to the annual disappearance of at least 500,000 hectares and up to 1 million hectares of mature forests

has been steadily declining (currently about 4,000 cubic meters per million metric tons of raw coal), but so has the output share of these mines. Specific consumption of timber in small mines, for which there are no reliable statistics, has been always much higher than in large enterprises. The total demand by this sector alone may be up to 25 percent higher during the next 20 years. Given China's rapid expansion of foreign trade, it is obvious that wood requirements for packaging and the need for pulp will be also increasing.

In addition, China's aging population will increase the demand for coffins. Assuming that about three-quarters of all burials (7.7 million in 1991) are interments and that a coffin requires a minimum of 0.25 cubic meters of finished lumber, at least 1.5 million cubic meters of timber are needed annually, requiring the cutting of at least 3 million cubic meters of trees; that total will increase by more than 20 percent as the average projected mortality of China's aging population rises from about 6.5/100,000 during the early 1990s to just over 8/100,000 in the year 2020.

As with estimates of declining farmland, assessments of the economic cost of China's deforestation must be based on figures that realistically reflect long-term trends rather than short-term aberrations. Careful appraisal of the available evidence indicates that the overcutting of China's mature forests—that is, harvesting above the average annual increment of wood in stands storing the largest volume of wood, harboring the greatest biodiversity, and providing the widest array of ecosystemic services—has recently proceeded at a rate of 50 million to 100 million cubic meters a year. With commercially useful phytomass averaging around 90 cubic meters per hectare, this loss is equivalent to the annual disappearance of at least 500,000 hectares and up to 1 million hectares of mature forests. When valued in terms of the lost supply of timber, this overcutting is estimated to cost—with lumber accounting for 40 percent of the cut volume and an average price at RMB 650 per cubic meter—between RMB 13 billion and RMB 26 billion per year.

The long-term impact on ecosystemic services includes diminished water storage capacity, reduced protection against wind and water erosion (rates are likely to increase by two orders of magnitude), and other effects that are difficult to quantify, such as changes to local and regional climate, contributions to changes in the biospheric carbon cycle and possible planetary warming, and consequences for national and global biodiversity. Monetization of these effects remains highly uncertain, with multipliers, implied or cited, ranging from 1.5 times to more than 20 times the value of the cut timber.[122] The already cited study of ecosystemic services provided by the Changbaishan forest reserve[123] estimates their value at about RMB 49,000 per hectare. Harvested timber (assuming 100 cubic meters per hectare of growing stock of which 50 percent becomes lumber) would have been worth about RMB 33,000 per hectare in 1990, resulting in a services/lumber ratio of roughly 1.5. Taking this multiplier as the minimum value translates to approximately RMB 20 billion to RMB 39 billion for the lost ecosystemic services from 0.5 million

to 1.0 million hectares of excessive cutting.

Much higher relative values have been imputed to forests in Europe, mainly because of their high recreational, biodiversity, and climate-modification worth. Most recently, the possibility of rapid global warming has also increased the value of forests as potentially major carbon sinks.[124] None of these amenities and services is a part of this conservative assessment.

Declining Water Availability

Huge increases in China's population and economic output have swelled nationwide water needs. The total population doubled between 1950 and 1990, the urban population quintupled, industrial output rose about 80-fold, and the area of irrigated farmland tripled—from 16 million to 49.8 million hectares. All of these trends will continue. The population will increase by at least 150 million people during the 1990s, and, if urban growth can satisfy the enormous outmigration flows from the countryside, China's cities could grow by more than 100 million persons.

This urban expansion, combined with the upgrading of housing stock in the cities, will multiply the pressure on China's water resources. Research done in Beijing shows that, when a three-person family moves from a traditional single-story *hutong* to a high-rise apartment, its water use goes up annually by at least 3 metric tons. Industrial production may more than triple during the 1990s, and, after a spell of stagnation and even a slight regression during the 1980s, the irrigated area is again increasing: it grew by 1.4 million hectares between 1991 and 1993.

China's total water resources can easily cover all of these needs, but only in a theoretical exercise that ignores their highly uneven distribution. In the Huang He basin in North China, for example, total water runoff available per hectare of cultivated land is less than one-eighth the average in the Yangzi River basin. This disparity worsened during the 1980s when a succession of dry years reduced the Huang He's flow to as little as two-fifths of the long-term mean and the river's normally low early summer flow ceased altogether for more than one month downstream from Jinan.

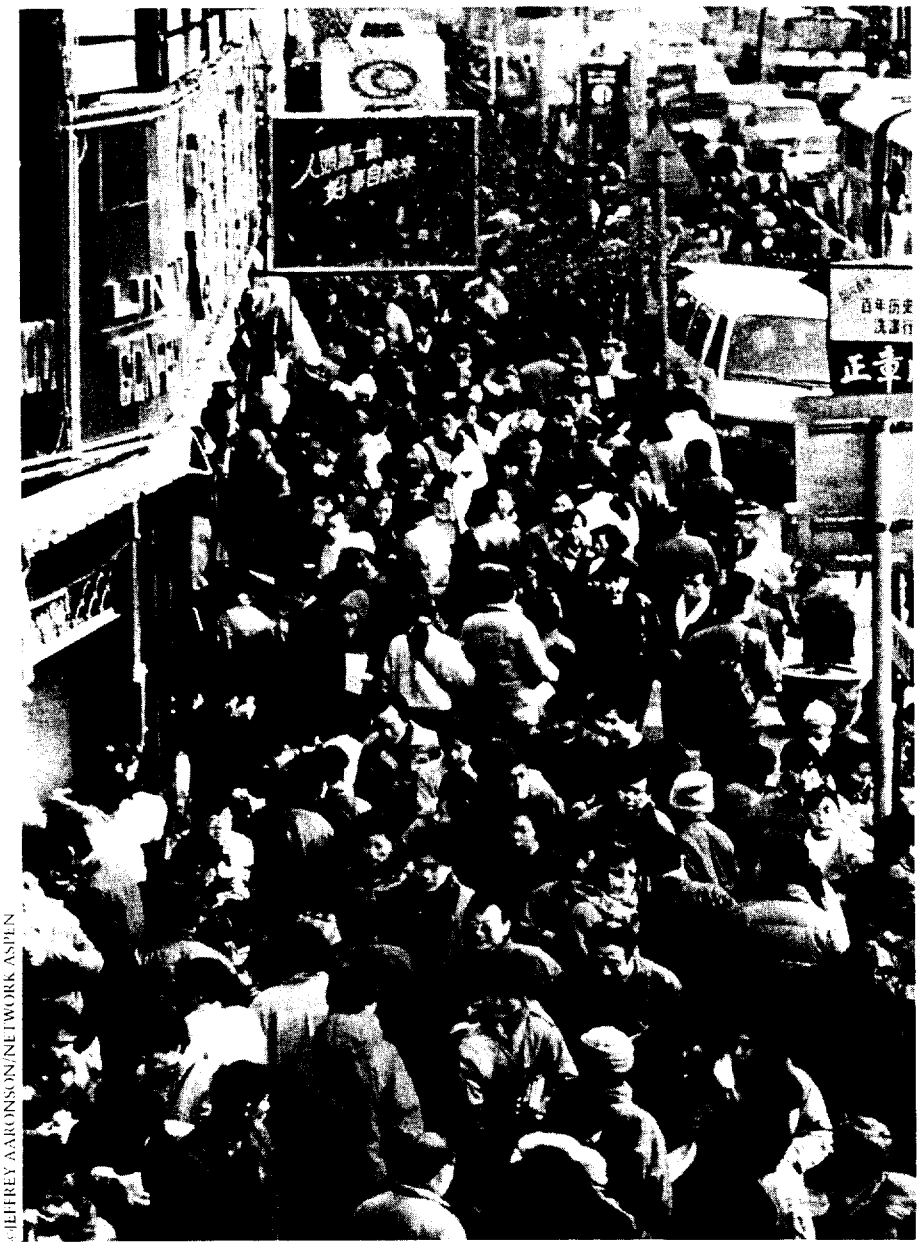
The recurrent northern runoff shortages have generated a high degree of reliance on underground water reserves, with consequent depletion of northern aquifers, drastically sinking water tables, and extensive lowering of surface water levels.[125] Beijing has been particularly hard hit.[126] Two generations ago its water table was just 5 meters below the surface in places, but it has been sinking by about 1 meter yearly. Today the city's more than 40,000 wells draw water from depths of about 50 meters. During the driest years of the 1980s, the annual drop surpassed 2 meters, and the surface subsidence (the usually gradual, but sometimes abrupt, sinking of the ground level caused by overexploitation of underground water) now covers an area of more than 1,000 square kilometers in and around the city. Annual water shortages during dry years now amount to between 600 million and 900 million metric tons, and, by the year 2000, the deficit is forecast to be at least 1.3 billion metric tons, about half the city's sustainable annual underground water supply. This situation—which has led to such dangerous necessities as the fetching of water in pails by orderlies to keep hospital emergency services running—has brought the very future of Beijing as China's expanding capital into question.

Water shortages in the North have been increasing in both scale and scope. In Tianjin, the North's second largest city near Beijing, surface subsidence affects about 7,300 square kilometers, or nearly two-thirds of the municipality's total area; annual drops are as high as 8 to 9 centimeters, causing serious building damage. Water shortages, which affected 154 large and medium-sized cities in 1979, spread to 200 cities in 1990. That year's urban water deficit was estimated at 15 million metric tons per day (i.e., 5.5 billion metric tons per year) and is forecast to be as high as 88 million metric tons per day by the year 2000.

Serious water shortages have gradually spread over a large part of the North. Perhaps the most stunning fact is that about 50 million persons in the countryside do not have enough water for basic daily use.[127] Shortages of water for irrigation and urban and industrial uses now affect some 585,000 square kilometers, an area larger than France. The supply is particularly restricted in Hebei and Shanxi provinces. More than a quarter of Hebei's farmland cannot be properly irrigated, one-quarter of Shanxi's irrigated fields cannot be guaranteed water during the growing period, and about 10 percent of Shanxi's peasants have chronic shortages of drinking water.

The direct economic costs of water shortages include reductions in crop yields and industrial output, personal discomfort (very difficult to estimate),

A projected water shortage of 1.3 billion metric tons by the year 2000 has brought the very future of Beijing as China's expanding capital into question.



JEFFREY AARONSON/NETWORK ASPEN

and damage to land and real estate resulting from surface subsidence in areas with excessive extraction of groundwater. The lack of disaggregated data makes it impossible to make separate estimates for the industrial and agricultural costs of water deficits in northern China's urban areas where a large share of water is used in suburban farming. In 1990 China's economy needed about 250 metric tons of water for every RMB 1,000 of GDP. Consequently, even if only 10 to 15 percent of the northern urban water deficit, that is, about 550 million to 800 million metric tons per year, were ascribed to ecosystemic degradation, this shortfall could generate output worth RMB 2.2 billion to RMB 3.2 billion. Of course, this assumes that no adjustments in production had been taken to overcome water shortages, whereas in reality better cultivation methods (for example, widespread use of plastic sheets) and water-saving measures in industry have made important inroads. Consequently, reducing the total losses by at least a third, to RMB 1.5 billion to RMB 2.1 billion, may give more realistic estimates.

A better approach to expressing the costs of water shortages is to total the increased municipal and industrial expenditures resulting from tapping deeper aquifers and to assess the costs of purification and recycling. Unfortunately, there is not enough information for either of these estimates; also, costs of recycling would have to be offset by lowered health, crop, and aquatic product losses from reduced water pollution.

An easier alternative is to express the urban water shortage in terms of forfeited sales. As the cost of 1 metric ton of treated water in China's northern cities should have been between RMB 0.2 and RMB 0.4 (in reality the highly subsidized price of RMB 0.12 to RMB 0.18 per metric ton was much below the production cost), the shortfall of 5.5 billion metric tons would have been worth about RMB 1.1 billion and RMB 2.2 billion. The minimum order of magnitude for subsidence costs can be estimated by assuming at least 50,000 kilometers of affected area, and land and property

damage worth no less than RMB 100 to RMB 120 per hectare: this would translate into annual costs of about RMB 500 million to RMB 600 million.

Crop yield losses are difficult to estimate because, even if the total irrigation water deficit is known with great accuracy, its ultimate impact will vary greatly with timing and crop selection. A very conservative set of assumptions is to see water shortages resulting from resource mismanagement affecting no more than 10 percent of the sown area and causing, on average, yield declines of no more than 5 to 10 percent. Assuming a mean production value of RMB 4,000 per hectare of irrigated land, the annual economic cost of this shortfall would be between RMB 3 billion and RMB 6 billion.

ADDING UP THE COSTS

Before summarizing this exercise I must reiterate its tentative nature and add a few more caveats. The completeness of the numerator (the costs of pollution and environmental degradation) is questionable not only because of the already described difficulties in incorporating known, but hard to quantify, health and ecosystemic effects but also because of the omission of an unknown number of specific effects that may be never considered unless one comes across a surprising report, such as one on recent damage to the silk industry in eastern China. The report noted that smoke from brick kilns in parts of Jiangsu has a high content of fluorine. As this element accumulates in mulberry leaves, it reduces the quality of silk and eventually causes higher silkworm mortality.[128] When silkworms are recycled as fertilizer, concentrated fluorine is transferred to the soil and reduces crop yields; in 1990 this effect resulted in losses of RMB(1990) 3 million in one Jiangsu county.

The results of the accounting exercise—most notably any conclusions about the relative impact of environmental degradation on China's economy—are further complicated by uncertainties about the denominator (China's GDP). This is true even if the exercise is limited to Chinese currency and if no monetary conversions for international comparisons are made. For decades Chinese statistics followed the Soviet practice that limited national accounts to the net material product of the society, an approach that ignores the contribution of services. In the early 1980s the Chinese also started to follow the Western System of National Accounts (SNA), and they published retrospective GNP totals since 1979. GDP totals derived from SNA procedures do not reflect the whole economy: they include neither black market transactions nor the barter and subsistence activities that are commonplace in poor and overwhelmingly rural countries. As a result, China's official GDP is undoubtedly undervalued. Recently published estimates using purchasing power parities indicate that the real value is at least three and as much as six times as high as the GDP level resulting from simple conversion using the official exchange rate.

Stressing and reiterating these weaknesses is, however, only part of the story. This exercise is not and cannot be a satisfactorily accurate and exhaustive investigation. Perhaps it is best viewed as an exploratory attempt to demonstrate the seriousness of the problem in a way that offers a foundation and gives encouragement—

either because of its positive aspects or because of its many weaknesses—to better inquiries. The division of the economic costs of environmental impacts into pollution and degradation categories is more a matter of convenience than a reflection of the complex situation. Despite a significant degree of overlap, however, this division is best justified in practical, planning terms: most pollution phenomena have relatively short-term technical fixes, whereas most environmental degradation processes require sustained long-term commitment to reverse undesirable trends.

Highly conservative estimates of the economic costs of China's air and water pollution totaled about RMB 30 billion in 1990, whereas a slightly less

Table 7. Estimates of environmental pollution costs in China in 1990

Category	Minimum (RMB millions)	Maximum (RMB millions)
Air pollution	11,000	19,200
Human health	3,800	6,500
Respiratory morbidity	2,500	4,500
Respiratory mortality	500	800
Lung cancer mortality	500	800
Cardiovascular mortality	300	400
Damage to crops	2,100	4,300
Damage to forests	800	1,700
Damage to materials	2,000	4,000
Household cleaning	2,300	2,700
Water pollution	9,700	14,000
Human health	4,100	6,700
Diarrhea and parasitic diseases	2,200	4,500
Hepatitis and dysentery morbidity	400	500
Liver cancer mortality	1,500	1,700
Aquatic production losses	1,400	1,700
Animal husbandry losses	200	300
Crop yield losses	400	500
Food sale losses	600	900
Industrial production losses	2,500	3,300
Treatment of ground water	500	600
Solid waste disposal	9,000	10,500
Total	29,700	43,700

restrictive—but still basically conservative—account adds up to about RMB 44 billion (Table 7). These aggregates would be, respectively, 1.7 percent and 2.5 percent of China's GDP in 1990.

Valuations of environmental degradation show wider ranges (Table 8). Uncertainties about the costs of soil erosion (especially lost nutrients) and the value of ecosys-temic services lost by the overcutting of mature forests are the main reasons for the nearly twofold discrepancy. A conservative estimate is about RMB 66 billion; a more liberal one is RMB 125 billion.

Limitations and Implications

Total estimates of China's environmental pollution and ecosystemic degradation in 1990 range from approximately RMB 95 billion to RMB 170 billion, which is equivalent to roughly 5.5 to 9.5 percent of the country's GDP. Where does this put the country in international comparison? Unfortunately, there have been few attempts to systematically evaluate the national economic costs of environmental degradation, and the available cases have included different sets of valuations and used substantially different accounting procedures.

Two prominent examples, a Dutch study for 1985 and a West German account for 1983–85, illustrate these problems very well. They ended up with very different conclusions: the Dutch estimated the annual cost of air and water pollution and noise at just 0.5 to 0.9 percent of the GDP, whereas the German total was 6 percent .[129] The main reason for the higher German estimate was that it allowed for the disamenity effects* of air pollution and for the impact of noise on property values.

These examples were essentially limited to pollution phenomena, and hence they clearly underestimate the total economic impact of environmental degradation. Undoubtedly, so does this broader exercise. I have stressed repeatedly the conservative nature of my estimates, and in some cases I have indicated how more inclusive assumptions would easily double the tabulated totals. At this point I should also reemphasize, how-

* The loss in comfort, pleasure (in, for instance, a blue sky), or convenience resulting from pollution.

Table 8. Estimates of environmental degradation costs in China in 1990

Category	Minimum (RMB millions)	Maximum (RMB millions)
Loss of farmland	1,600	4,100
Lost harvests	600	1,600
Lost ecosystemic services	1,000	2,500
Soil erosion	11,000	26,400
Decreased crop yields	300	800
Loss of nutrients	5,000	15,000
Replacement of lost water storage	500	700
Lost crop production	400	600
Silting of hydrogeneration reservoirs	1,300	1,800
Clearing of silted canals	1,400	1,800
Cleaning of urban water supplies	400	500
Crop yield losses in flooding	700	2,200
Material damage in flooding	1,000	3,000
Farmland degradation	4,200	8,000
Declining soil organic matter	200	600
Waterlogging, salinization, etc.	3,300	6,500
Disposal of solid waste	700	900
Land reclamation after mining	100	200
Degradation of grasslands	3,700	5,400
Lost ecosystemic services	900	1,300
Lost mutton production	800	1,100
Lost wool production	2,000	3,000
Loss of wetlands	200	500
Forest mismanagement	39,900	71,500
Overcutting	33,000	60,000
Timber	13,000	21,000
Lost ecosystemic services	20,000	39,000
Forest fires	5,000	9,000
Pest outbreaks	1,900	2,500
Water shortages	5,000	8,700
Crop yield losses	3,000	6,000
Industrial production losses	1,500	2,100
Ground subsidence	500	600
Total	65,700	124,800

ever, a relatively large number of factors that are completely missing from my account. Tabulation of the most prominent of these, together with estimates of their costs expressed at the most likely orders of magnitudes, shows that it would be very realistic to extend the estimated costs by totals amounting to several tens of billions of RMB (Table 9).

Conclusions

Perhaps the most sensible conclusions can be summarized as follows. Given the highly conservative nature of the estimates presented in this report, it is extremely unlikely that the economic cost of China's environmental pollution and ecosystemic degradation was less than 5 percent of the country's GDP in 1990. A range of 6–8 percent is the most likely conservative estimate. Values of approximately 10 percent would be consistent with a more comprehensive, although still not necessarily complete, coverage, whereas inclusion of a number of elusive factors could raise the rates to about 15 percent of the country's annual GDP, a share much higher than any estimate available for an affluent Western economy. These estimates contrast sharply with China's actual spending on environmental protection: during the 1980s China's overall investment in this area was equivalent to between 0.56 percent and 0.81 percent of annual GDP, substantially less than the 1.5 percent recommended by the country's leading environmental experts. This relative neglect is to change soon: Qu Geping, chairman of the National People's Congress Environmental and Resources Protection Committee, announced in December 1995 that the country is planning to raise the share to 1.5 percent by the year 2000.[130]

Again, I must reiterate that this has been only an exploratory exercise based on a limited amount of information, requiring repeated assumptions, and resulting in no more than basic approximations open to justifiable critique. As such, it does not stand alone: even less comprehensive attempts at environmental valuation based on better information are beset by enormous uncertainties.

On the other hand, I would argue that the inherent weaknesses of this accounting exercise, the uncertainties about specific cost estimates, and the relative reliability of more or less conservative assumptions are less important than the undeniable bottom line. The evidence is sufficiently robust to allow two key conclusions. First, China's current transformation of the environment already carries economic costs several times higher than the country's annual spending on environmental protection: doubling, or tripling, of these outlays would easily meet even the most stringent criteria for a high benefit-cost action.

Second, given that the economic burden of China's environmental pollution and ecosystemic degradation may already equal as much as 15 percent of its annual GDP, the country's recent aggressive expansion in mining, manufacturing, and transportation, as well as the rapid rate of urbanization and widespread expectations of further large gains in personal affluence, must be seen as matters of serious concern.

China cannot be another Taiwan, South Korea, or Japan. If China consumed resources at the South Korean

Table 9. Missing estimates of China's environmental degradation

	Likely annual costs (RMB)			
Category	10–100 million	100–1,000 million	1–10 billion	More than 10 billion
Pollution				
Photochemical smog			x	
Toxic wastes			x	
Short-lived radioactive wastes	x	x		
Long-lived radioactive wastes			x	x
Decreased ocean fish catch	x	x		
Lost amenities				
Human suffering and discomfort			x	x
Noise			x	x
Reduced visibility		x	x	
Recreation				
Forests			x	x
Wetlands and lakes	x	x		
Beaches	x	x		
Ecosystemic services				
Loss of biodiversity			x	x
Biospheric stability				
Emissions of greenhouse gases			x	x

or Taiwanese level and imported crude oil and grain at rates comparable to those of other rapidly growing East Asian economies, it would need more energy and more cereals than are currently available on the world market. Securing the largest possible share of its energy and food needs from domestic sources will be important not only for China's economic progress but also for global stability. Such a strategy can succeed, however, only when China uses its resources efficiently and makes protection of its environment, and a gradual shift to more sustainable ways of running its economy, a matter of high priority.

POSTSCRIPT

After I completed this study, I was able to secure a grant for a group of Chinese scholars to prepare, quite independently, similarly comprehensive estimates of China's environmental pollution and degradation.* Professor Mao Yushi, director of the Unirule Institute, was the study's coordinator, and the three contributors were Wang Hongchang (deforestation), Ning Datong (land degradation), and Xia Guang (water and air pollution). Their estimates, expressed in 1992 RMB, added up to about RMB 20 billion for water pollution, RMB 50 billion for air pollution, RMB 35 billion for farmland and grassland degradation, and RMB 245 billion for deforestation. These totals should be reduced by about 10 percent to obtain comparable values in terms of 1990 RMB values.

The two studies are less than 20 percent apart in estimating the cost of farmland degradation and water shortages and the total cost of water pollution. The substantial difference for air pollution is caused largely by a much higher estimate of health costs in the Chinese study. Values for the cost of deforestation are not directly comparable, as Wang Hongchang quantified the impacts on the basis of overall difference between the current forest area and the potential natural coverage, whereas I limited my estimates to the cost of recent losses. In general, the Chinese study confirms the conclusions of this valuation exercise and clearly indicates that the overall costs of China's environmental changes are on the order of 10 percent of the country's GDP, a burden clearly justifying much higher investment in environmental protection and management.

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