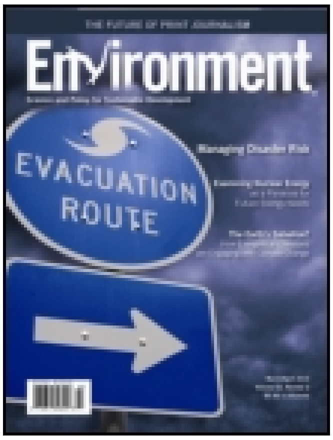

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China Shoulders the Cost of Environmental Change

By Vaclav Smil

Ecologists today have at their disposal a great deal of evidence about the processes that degrade our environment, ranging from coastal eutrophication to tropical deforestation. They have come to understand the intricacies of human-induced changes such as acid deposition and heavy metal accumulation. But they do not have realistic assessments of the economic losses that result from environmental pollution and ecosystem degradation. Possession of these kinds of numbers would strengthen their arguments for environmental management considerably. Persuasive figures could help reorient public policy, environmental law, and investors' thinking in favor of effective preventive action.

So, why haven't these figures been developed? First, there are (as yet) no generally accepted procedures for conducting such evaluations.[1] These methodological uncertainties leave individual researchers with no choice but to use subjective judgments when deciding which variables to include and how to treat them.

Suppose, for example, researchers wanted to quantify the health effects of chronically high levels of urban air pollution. They could take the more minimalist approach, limiting the analysis to the value of the labor time lost due to higher upper-respiratory morbidity. Or they could attempt a more all-encompassing evaluation that would put a price on every individual discomfort and include the cost of premature death. As these researchers would quickly discover, the former approach is much easier than the latter. While a rich and fascinating literature on the price of personal suffering and the value of life does exist, objective criteria for putting a monetary value on respiratory discomfort, physical limitations, and anxiety induced by asthma attacks do not. As far as the value of life is concerned, actuarial practices, economic considerations, and moral imperatives offer estimates that may differ widely—sometimes by up to an order of magnitude.[2]

Having a standard set of procedures would not really simplify the task, however. The basic problem is that the kinds of specific figures required as basic inputs in such calculations are typically unavailable even in affluent countries, which have long had good statistical serv-

ices.[3] This makes it impossible for researchers to avoid making subjective choices and simplifying assumptions, even though this weakens the persuasiveness of the eventual bottom line. As it is, the cumulative effect of even

OMNI-PHOTO COMMUNICATIONS—ERIC KROLL

Strict birth control policies have slowed the relative growth of China's population, but this nation of 1.2 billion can still expect to add an additional 13 million people each year.

small departures from reality can easily halve or double a final figure.[4]

The second and perhaps most significant obstacle is the impossibility of putting a meaningful price on lost or reduced environmental services. For example, suppose a peasant living on a treeless plain takes straw from a field to light a fire to cook a meal. How can the loss of that straw be valued? The loss of the plant nutrients in the straw could be expressed rather easily by equating it with the cost of the synthetic fertilizers needed to replace those nutrients. But the straw also improved the soil's capacity to retain water and provided food for bacteria, fungi, and numerous invertebrates. Without these life forms, the soil will not be as productive and may be unable to sustain farming. How can these losses be valued?

Should these obstacles, daunting as they are, keep us from trying to evaluate economic cost? Absolutely not. It is simply necessary to always keep the limitations of the process in mind when interpreting the results. The evaluations will provide useful ranges of approximations—not correct single-figure answers. They will all be incomplete, and even the most comprehensive ones will almost certainly undervalue the real impact human actions have on the long-term integrity of environmental quality. However, despite these limitations, these assessments can be valuable, particularly when looking at the costs of environmental change in countries experiencing rapid growth, such as China.

A nation of more than 1.2 billion people, China's population grows by at least 13 million each year. This is the equivalent of adding the population of France in less than five years.[5] During the 1980s, China's gross domestic product (GDP) grew faster than that of all other nations except South Korea. In the early 1990s, China posted annual growth rates of up to 14 percent in GDP, the highest in the world.[6] But this rapid growth has exacted a price. Irrational industrial and agricultural practices have left scars, and the ill effects of pollution already mar the air, water, and land of this nation endowed with absolutely large but on a per capita basis relatively limited resources.[7]

Attempts to assess the economic cost of these changes have frequently met with difficulties. China's official government agencies are filled with masses of uncooperative bureaucrats prone to treat any unflattering figure as a state secret. Dubious statistics and unverifiable claims also abound. It seems to be one thing for the Dutch or Germans to assign a cost to environmental degradation in their countries and another thing entirely for the Chinese to do so.[8]

That said, the Chinese actually did some of the earliest studies. One, begun in 1984 and published in 1990, estimated the cost of pollution to be about 6.75 percent of the nation's annual GDP in 1983.[9] In response to this work, and with the goal of quantifying at least some of the major consequences of the degradation of China's ecosystems, I began work on a more comprehensive evaluation in 1993.[10] As this assessment was being completed, a group of Chinese researchers began a similarly comprehensive independent evaluation.[11]

Having both of these studies available creates an unparalleled opportunity to appraise the economic impact of environmental change in China. The following discussion will review some of the country's most important environmental concerns, highlight key conclusions from both studies, and explain the reasons for some of the major differences in their results. Readers interested in the studies' detailed assumptions are urged to refer to them specifically.

Air and Water Pollution

A small pioneering opinion survey published in China in 1994 uncovered some interesting facts. First, the public ranked air and water pollution second only to earthquakes and floods when asked to list environmental hazards. Respondents with science or engineering degrees, however, put the two pollution risks ahead of natural disasters.[12] China's severe air pollution problem stems from two sources: a traditionally high dependence on coal (whose combustion produces classic smog composed of suspended particulates and sulfur dioxide) and recent rapid increases in vehicular traffic (whose emissions of volatile organic compounds, nitrogen oxides, and carbon monoxide play key roles in the complex reactions that create photochemical smog).

While Chinese coal is of fairly good quality, only about one-fifth of it is cleaned and sorted before combustion. Typical conversion efficiencies remain very low in tens of millions of household stoves and thousands of small industrial and commercial boilers throughout the country, resulting in extraordinarily high emission factors per unit of delivered energy.[13] The high density of urban areas and their tendency to be both residential and industrial, improperly vented household stoves, and the burning of smoky biomass fuels in rural areas aggravate the situation.

Fossil fuel combustion in China now produces close to 20 million metric tons of sulfur dioxide and about 15 million metric tons of particulates a year. Monitoring shows the long-term averages of both pollutants to be multiples of the maximum limits recommended by the World Health Organization (WHO).[14] For example, WHO has established a limit of no more than 40–60 micrograms per cubic meter of sulfur dioxide as the annual mean. But even the cleanest suburbs of Beijing average 80 micrograms per cubic meter a year. In the city's most polluted neighborhoods, the annual mean is double that value. Still, these levels are low when compared to annual means of more than 400 micrograms per cubic meter in Taiyuan and Lanzhou and more than 300 micrograms in Linfeng, Chongqing (Sichuan), and Guiyang (Guizhou).

Particulates and sulfur dioxide cause relatively little damage to crops. Most of the yield losses are seen in suburban vegetable farms. They do, however, inflict considerably greater damage on materials, above all to buildings and corrodible surfaces. As acid deposition intensifies in the rainy South, the amount of this kind of damage will only increase.[15] A number of worrisome human health risks are also associated with this kind of pollution. At least 200 million Chinese are exposed to annual particulate concentrations of more than 300 micrograms per cubic meter; at least 20 million are exposed to twice that level. With the spread of new industries across the country, between 100 million and 200 million rural inhabitants may already be breathing air nearly as polluted as that in the cities.

Such high exposure levels call to mind conditions in the cities of western Europe and North America two to four generations ago. As was the case then, these high levels of exposure contribute to higher incidences of respiratory diseases, ranging from upper-respiratory infections to lung cancer. But assessing the share of these diseases attributable to outdoor air pollution alone is particularly difficult in China for two reasons. First, most people are also exposed to very high levels of indoor air pollution from inefficient stoves. Second, the nation abounds with smoking addicts.[16]

Polluted water is even more ubiquitous than polluted air in China. Several years ago, a survey of nearly 900 of the country's major rivers found that more than four-fifths of them were polluted to some degree, more than 20 percent so badly that their water could not be used for irrigation.[17] Drinking water meets official quality standards in only 6 out of the 27 largest cities that draw on surface sources and in just 4 out of those 27 that use underground sources.

It is common practice to release untreated municipal wastes into rivers, even in large cities. Half of Shanghai's waste is discharged into the Yangtze River and Hangzhou Bay. The Songhua River and Ji Canal, which flow through both the provinces of Jilin and Heilongjiang, still contain tens of metric tons of mercury, the legacy of uncontrolled releases prior to 1977 that resulted in mercury concentrations higher than those recorded in Japan's Minamata Bay.[18]

Enormous numbers of small to medium-sized rural and township enterprises have proliferated outside China's large cities in recent years. In Jiangsu Province, which surrounds Shanghai, roughly one such enterprise can be found per square kilometer. But along with jobs these plants have brought a variety of water pollutants

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THE STOCK MARKET—MICHELE BURGESS

Coke kilns in Guiyang province release a noxious mix of pollutants, including sulfur dioxide and particulates, whose inhalation is linked to a number of respiratory diseases.

China

(continued from page 9)

into the Chinese countryside. Unknown volumes of untreated waste from these plants get dumped into streams and networks of canals, contaminating the water used for drinking (about half of the population draws its drinking water from surface sources), irrigating fields, and watering animals.

In addition to such common industrial pollutants as industrial oils, phenols, and heavy metals, high levels of nitrates leached from heavy fertilizer applications befoul the water. As the world's largest consumer of synthetic nitrogen fertilizers, China annually applies an average of around 140 kilograms of nitrogen per hectare. In the most intensively cultivated provinces, this figure surpasses 300 kilograms per hectare. Combined with animal and human wastes, these nitrogen loadings will eventually lead to serious nitrate contamination.[19]

The pollution of its water has created a number of negative economic impacts for China. Fish catches in streams and reservoirs have declined. Red tides now occur with greater frequency, jeopardizing the domestic shrimp aquaculture industry. Incidence rates of tumors among livestock have increased, as have those of cancers of the liver, stomach, and esophagus in humans. Studies of the localities suffering from the worst water pollution have found the incidence rate of cancers of the digestive system to be 3 to 10 times higher there than in unpolluted communities. These studies also uncovered instances of anemia, skin diseases, enlarged livers, premature hair loss, and a higher incidence of congenital deformities. Thanks in part to water pollution, viral hepatitis and dysentery top the list of infectious diseases in China.

In the countryside, waterborne pathogens and the eggs of parasites, which are concealed in organic wastes that are recycled to cropland, continue to be a major problem. The frequency of ascariasis, ancylostomiasis, and trichuriasis among China's vegetable farmers exceeds 90 percent in some regions.[20] The impossibility of using polluted water in industrial and agricultural production has also led to substantial economic losses even as the government has incurred the additional costs of tapping new resources.

My calculations put the total cost of China's air and water pollution at roughly 30 billion to 45 billion 1990 yuan. The Chinese study came up with a total close to 100 billion 1992 yuan. Even if the more conservative estimate were increased by about 20 percent to account for China's high rate of inflation during the early 1990s, the estimates of the Chinese study are still considerably higher. As Table 1 on this page shows, much of the explanation for these differences lies in the studies' treatments of the impact of air and water pollution on human health.

The two major factors are different assumptions about population totals exposed to particular pollution levels and different costs ascribed to typical treatments or lost labor hours. As far as the total of urban populations exposed to excessive air pollution is concerned, the two studies do not differ all that much. But, when it comes to averages of the costs of treating chronic bronchitis and lung cancer, they do. The Chinese study uses average treatment costs of 2,100 and 12,700 yuan, respectively. I estimated the same costs on the basis of a different set of Chinese figures as 800 and 5,000 yuan, respectively. Such disparities are typical among the many previous studies that also attempted to assess the toll pollution takes on human health.[21]

Changes in Land Use and Soil Degradation

This broad category embraces a wide range of phenomena, from the desertification of China's extensive interior grasslands to the disappearance of its coastal marshes. The most pressing problems, however, are the

Table 1. Economic costs attributable to air and water pollution and solid waste disposal

Category	Estimated costs in billions[a]	
	Smil (1990 yuan)	Xia Guang (1992 yuan)
Air pollution[b]	11.0-19.2	57.9
Damage to human health	3.8-6.5	20.2
Damage to plants	2.9-6.0	7.2
Damage to materials	2.0-4.0	16.5
Acid rain[c]		14.0
Water pollution[b]	9.7-14.0	35.6
Damage to human health	4.1-6.7	19.3
Losses of food production	2.6-3.4	2.5
Industrial losses	2.5-3.3	13.8
Solid waste disposal	9.0-10.5	5.1
Total	29.7-43.7	98.6

[a]1992 values are approximately 20 percent higher than 1990 values due to inflation. Thus, to convert 1990 values to 1992 values, increase them by 20 percent.
[b]Because some minor subcategories are not shown, the listed values may not add up to category totals.
[c]Smil's estimates for acid rain damage are included in the other air pollution categories.
SOURCE: V. Smil.

loss of farmland and the qualitative decline of arable soils. A combination of two factors explain these changes: China's relatively low per capita availability of agricultural land and the expectation that its population will swell by at least 300 million over the next 25 years.

China actually has more arable land area than the total of 95 million hectares claimed by the State Statistical Bureau. The best estimates (based on sample surveys and remote sensing) lie somewhere in the range of 120 million to 140 million hectares.[22] This means that in per capita terms China still has more than twice as much farmland as South Korea and Japan, its truly land-poor East Asian neighbors.

At the same time, however, official totals of recent losses of arable land may err on the low side. Cumulative losses over the past 40 years total to more than all of Germany's farmland. Since 1980, China has lost about half a million hectares annually. Much of this land was of good quality: Alluvial soils in the coastal provinces have been eaten up at the fastest rate by urban and industrial expansion.

THE STOCK MARKET—ANDREW HOLBROOKE

The water used for irrigation often contains industrial oils, phenols, and heavy metals.

Declines in soil quality resulting from increased soil erosion and a decrease in the extent and intensity of traditional recycling of organic waste have also adversely affected agricultural production. Improper irrigation and more intensive cropping, which relies on increased applications of agrochemicals, are the other two key culprits lurking behind the declines in soil quality.

A nationwide survey conducted on almost half of China's farmland identified various degrees of excessive soil erosion on 31 percent of the land. The phenomenon does not occur only in regions naturally prone to high erosion rates, such as China's Loess Plateau. In Sichuan, the country's most populous province with a population of more than 110 million, 44 percent of fields were eroding beyond a sustainable level during the late 1980s. This figure represented a fourfold increase in erosion compared to the early 1950s. Annual erosion losses on two million hectares of cultivated slopeland (nearly one-third of Sichuan's total) averaged 110 tons per hectare.[23] To get a sense of scale, consider that in the United States annual water erosion rates recently averaged just slightly more than 9 tons per hectare and wind erosion rates amounted to a little more than 7 tons per hectare. This combines for a total annual average loss of about 16 tons per hectare.

To quantify the economic costs of farmland losses and deteriorating soil quality, I calculated the value of lost harvests, decreased yields (or lower livestock production), and lost nutrients from eroded soils. I also estimated the costs (implicit as well as explicit) of siltation in reservoirs and canals (used both for irrigation and as sources of urban water supplies), higher damage from flooding, and the loss of key ecosystem services provided by lost paddy fields and wetlands and degraded grasslands.

As it turned out, the Chinese study's assessment of detrimental effects arising from changes in land use and soil degradation was remarkably similar. Given the nature of this accounting exercise, the two sets of calculations agree quite closely: My median value, (38.6) adjusted for inflation, differs from the Chinese total by less than 10 percent (see Table 2 on page 35).

Deforestation

When it came to the analysis of deforestation in China, the two studies did not arrive at such similar conclusions. In fact, some of the most significant differences between them crop up in this analysis. By far the greatest disparity centers on estimates of the economic consequences of deforestation. This huge difference does not result from irreconcilable assumptions concerning soil erosion, stream silting, or the loss of water retention capacity. Indeed, a close look reveals greatly similar assumptions on all these accounts. The reason for the disparity lies in fundamentally different approaches to the problem.

The Chinese study adopted what could perhaps be best described as a deep ecological perspective. It estimated that China has lost approximately 290 million hectares of forest since the beginning of the country's history. Roughly 50 percent of this loss can be attributed to the conversion of forestland to farmland, settlements, and transportation networks, the unavoidable consequences of an ancient civilization's growth. The other half of the loss represents the costs of excessive logging. This land could have remained forested if properly managed and could now be harvested on a sustainable basis. Proceeding from these assumptions, the Chinese study calculated the impact of this excessive deforestation on the desiccation of the northern and northwestern regions of the country and on accelerated erosion, which causes streams and reservoirs to fill with silt, thereby leading to greater damage during floods.

In contrast, my study estimated the environmental cost of deforestation on the basis of the current extent of excessive cutting of mature growth. Curiously, if one were to take China's official statistics at face value, it would be impossible to take this approach. These statistics claim that China's total wood increment has surpassed the amount cut annually during most of the early 1990s. If this were true, there would be no net deforestation. But even if one accepted this obviously exaggerated statement, it appears in a different light once combined with an awareness of the changing composition of China's forests.

During the early 1990s, no less than three-fourths of China's timberlands were young or middle-aged stands. The growing stock ready for harvesting in mature forests amounted to less than one-fifth of all standing timber. This total could be cut in just seven to eight years. The amount of stock in forests approaching maturity will decline from almost one-third of all timber in the late 1980s to less than one-seventh by the year 2000.

According to figures compiled by the Chinese Ministry of Forestry, 25 out of the 131 state forestry bureaus in the most important timber production zones had exhausted their reserves by 1990. Only 40 of these bureaus post figures showing that they can harvest up to the year 2000. By 2000, almost 70 percent of China's state forestry bureaus will basically have no mature trees left to fell.[24] Furthermore, the official figure for the average amount of wood growing in forest plantings—28.27 cubic meters per hectare—makes it quite clear that the new plantings (whose growing stock may be yielding the statistical wood surplus) cannot hope to replace the felled mature forests, which had a growing stock of at least 70 to 80 cubic meters per hectare, for many decades. Consequently, even if it is real, the recent quantitative growth of Chinese forests hides a major qualitative decline.

In any case, estimates of the economic cost of deforestation in China should be based on figures that realistically represent long-term trends rather than capture short-term aberrations. Careful appraisal of the available evidence indicates that the overcutting of mature forests—in other words, harvests above the average annual increment of wood in stands that store the largest volume of phytomass, harbor the greatest biodiversity, and are able to better provide various ecosystem services than recent plantings—has been proceeding recently at a rate of at least 50 and up to 100 million cubic meters per year.

With the volume of harvestable wood averaging around 90 cubic meters per hectare, this loss translates into the disappearance of half a million to one million hectares of mature forest per year. In terms of the loss of future timber supplies alone, this overcutting would cost between 13 billion and 26 billion yuan a year. With the disappearance of these trees, however, comes the weakening or outright loss of some of the crucial functions they performed. The soil's water storage capacity diminishes. The land becomes even more vulnerable to wind and water erosion (whose rates are likely to increase by two orders of magnitude). And the local and regional climate may change. While the effects of such changes are difficult to quantify, they could contribute to changes in the biospheric carbon cycle and possibly global warming, which will have dire consequences for China's and Earth's biodiversity.

Putting a price on these effects remains a highly uncertain process. Multipliers range from 1.5 to more than 20 times the value of the cut timber.[25] Chinese foresters have estimated the combined ecosystem benefits of mature forests to be between 8 and 25 times the profit from harvested timber sales. For example, a detailed study of the Changbaishan natural reserve in Jilin concluded that to replace the forest's water storage capacity with a reservoir, control soil erosion by terracing the slopes, and use pesticides rather than forest-sheltered birds to control insects the cost would be about 49,000 yuan (in 1990 monies) per

Table 2. Economic costs attributable to changes in land use and soil

Category	Estimated costs in billions[a]	
	Smil (1990 yuan)	Xia Guang (1992 yuan)
Farmland loss and degradation	5.8-12.1	12.5
Soil erosion	11.0-26.4	17.2
Reduced crop yields	0.3-0.8	0.4
Loss of nutrients	5.0-15.0	16.2
Reservoir silting	1.3-1.8	0.6
Clearing clogged canals	1.4-1.8	
Flooding damage	1.0-3.0	
Deterioration of grasslands	3.7-5.4	3.3
Total	20.5-43.9	35.8

NOTE: Because some minor subcategories are not shown, the listed values may not in fact add up to category totals.
[a]See Table 1 on page 33 for conversion from 1990 yuan to 1992 yuan.
SOURCE: V. Smil.

hectare, more than 20 times the value of sustainably harvested timber from the same area.[26]

Naturally, this ratio will rise if the forest's contributions to local and regional climate control and the value of its preservation of biodiversity are factored into the equation. Considerable value could also be imputed to the forest's future recreational worth and, in the long term, to the value of forests as carbon sinks. But even using 1.5 as the minimum multiplier value, the cost of lost ecosystem services due to excessive cutting ranges between 20 billion and 39 billion yuan. Including the value of timber lost due to unsustainable harvest methods and forest fires brings the grand total cost for forest mismangement up to 40 billion to 70 billion yuan.

While I based my calculations on annual losses of half a million to one million hectares, the Chinese study based their estimates on a cumulative total loss of about 140 million hectares. Interestingly, the Chinese study's estimate of the cost—245 billion yuan—did not include any adjustments for lost ecosystem services, which represented the highest share of my estimates. If these costs were included, the unusual historical approach the Chinese took would have ended up with an even higher total. Their approach does have one advantage, however. It calls attention to the true extent of human impact on China's forests. On the other hand, some of the costs estimated in one part of the study were also considered in another (the effects of soil erosion in particular) so a simple addition of the two sets of estimates would involve some double-counting.

Wider Perspectives

Although both studies were intended to be as comprehensive as possible, in the end a number of critical effects had to be dropped from consideration. Major impacts that could not be quantified because of a lack of basic information included the effects of photochemical smog in and near China's large cities, damage attributable to China's nuclear weapons sector, declining fish catches in China's seas, and the foregone recreational value of lost forests, wetlands, and beaches.

Perhaps most importantly, neither set of calculations tried to attribute any monetary value to human discomfort and suffering. These reactions are provoked not only by excessive morbidity and premature mortality, but also from chronic exposure to high levels of noise in China's cities.[27] Finally, neither study could ascribe any definite value to China's loss of biodiversity and to the country's already huge and rising contribution to greenhouse gas emissions, a highly worrisome source of potential biospheric instability.

Both sets of calculations (the Chinese estimate of deforestation costs aside) are based on clearly conservative assumptions. Consequently, there can be no doubt that the economic burden of environmental pollution and ecosystem degradation in China was no less than 5 percent of the country's GDP in the early 1990s. The most likely conservative estimate falls somewhere in the range of 6 to 8 percent. Values around 10 percent would be consistent with a more comprehensive, although still far from all-inclusive, assessment. If prices were ever put on a number of the more elusive factors, the rate could conceivably rise to around 15 percent of annual GDP.

These burdens greatly surpass China's recent spending on environmental protection. During the 1980s and early 1990s, annual investment in this area equalled just 0.56 to 0.81 percent of GDP. Only in 1996 did officials promise to raise spending on environmental protection to just more than 1 percent by the year 2000. Even this raise, however, would be an order of magnitude lower than the most likely economic cost.

It is difficult to compare these burdens to those in other countries because converting yuan into a major currency such as the U.S. dollar is problematical. Using the official yuan-dollar exchange rate (the method favored until very recently by the World Bank) greatly underestimates the real values, putting China's GDP at less than $500 per capita. On the other hand, using a rate based on purchasing power parity (the approach favored by the International Monetary Fund) clearly exaggerates the real values, putting China's 1995 per capita GDP at nearly $3,000.

The World Bank's latest study argues that China's actual per capita gross domestic product in 1995 was about $2,000. This rate implies a purchasing power parity rate roughly four times the official exchange rate.[28] Using this conversion, the annual economic burden of air and water pollution would amount to about $50 billion (using the Chinese study's total). The annual price tag for land degradation and excessive deforestation comes to around $20 billion (using the Chinese study's total). My lowest estimate of the same cost is no less than $40 billion. Even the lowest likely grand total of about $90 billion U.S. (1992 value) is a huge sum, slightly larger than the value of all of China's exports in 1992.

In closing, the dual nature of these valuations must be stressed. These two studies were exploratory exercises based on a necessarily limited amount of information and requiring repeated assumptions. As such, they can make no claims to complete accuracy, can give no more than basic approximations, and are open to justifiable criticism. At the same time, all of their inherent weaknesses and uncertainties cannot negate the message carried by the bottom line.

First, there can be no doubt that recent environmental changes in China already carry economic costs roughly an order of magnitude higher than the country's annual spending on environmental protection. Even if the government tripled or quadrupled its outlays, they would still easily meet even the strictest benefit-cost criteria. Second, given the fact that the economic burden of environmental pollution and ecosystem degradation may already exceed one-tenth of China's annual gross domestic product, its recent aggressive quest for modernization must be a matter of serious national and international concern.

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NOTES

1. For a detailed survey of possible valuation techniques, see A. J. Dixon et al., *Economic Analysis of Environmental Impacts* (London: Earthscan, 1994).

2. A. M. Freeman, *The Measurement of Environmental and Resource Values* (Washington, D.C.: Resources for the Future, 1993); and S. E. Rhoads, ed., *Valuing Life: Public Policy Dilemmas* (Boulder, Colo.: Westview Press, 1980).

3. This problem is obvious when one looks at the analytical framework recommended by the United Nations for national assessments of environmental impacts. See United Nations, *Integrated Environmental and Economic Accounting* (New York, 1993).

4. For example, estimating that 80 percent of the people in a region are exposed to excessive concentrations of a pollutant whose effects cause a 40 percent rise in the incidence of upper-respiratory morbidity, and that a typical illness event is associated with a 30 percent increase in absence from work, there will be roughly a 10 percent rise in lost labor hours. Changing the fractions marginally to, respectively, 70, 30, and 20 cuts lost hours by more than half.

5. Thanks to a generation of fairly strict birth controls, China's relative population growth, recently at just around 1.1 percent a year, is much lower than in any other populous modernizing nation (India's rate has been about 1.9 percent, Brazil's 1.6 percent). However, the huge base makes the absolute additions still highly taxing.

6. China's inflation-adjusted gross domestic product averaged 9.4 percent a year between 1980 and 1991, compared to South Korea's 9.6 and India's 5.4 percent. Since 1991, China's growth rate of just above 10 percent has been unmatched worldwide.

7. For a comprehensive survey of China's current environmental ills, see V. Smil, *China's Environmental Crisis* (Armonk, N.Y.: M. E. Sharpe, 1993); and R. L. Edmonds, *Patterns of China's Lost Harmony* (London: Routledge, 1994).

8. Two studies—a Dutch one calculating pollution costs in 1985 and a West German account for 1983-85—ended up with very different conclusions. The Dutch study put the annual cost of air and water pollution and noise at just 0.5–0.9 percent of the country's gross domestic product, while the German total was 6 percent, an order of magnitude higher. See J. Nicolaisen et al., "Economics and the Environment: A Survey of Issues and Policy Options," *OECD Economic Studies* (Spring 1991): 7–43. The main reason for the higher German value lay in their accounting for the physical impact of air pollution now and for the impact of noise on property values.

9. National Environmental Protection Agency, *Environment Forecast and Countermeasure Research in China in the Year 2000* (Beijing: Qinghua University Publishing House, 1990).

10. V. Smil, *Environmental Problems in China: Estimates of Economic Costs* (Honolulu, Hawaii: East-West Center, 1996).

11. M. Yushi et al., *Economic Costs of China's Environmental Change* (Report prepared for the Project on Environmental Change and Security, American Association of Arts and Sciences, Cambridge, Mass., 1997). Even before I completed my work, I thought it would be interesting if a small group of Chinese researchers undertook a similarly comprehensive evaluation independently. A comparison of the two studies could show both the usefulness and the limitations of these valuations. With the support of the Project on Environment, Population and Security directed by Thomas Homer-Dixon at the University of Toronto, I was able to ask Professor Mao Yushi, a noted Chinese economist, a member of the Chinese Academy of Social Sciences (CASS), and now the director of the Unirule Institute of Economics in Beijing to commission studies of the economic costs of environmental pollution, deforestation, and land degradation in China. Yushi chose Professor Wang Hongchang of CASS to prepare a paper on deforestation and Professor Ning Datong of the Beijing Normal University to write about land-use changes. He selected Xia Guang of the National Environmental Protection Agency to work up an evaluation of the costs of air and water pollution.

12. Z. Jianguang, "Environmental Hazards in the Chinese Public's Eyes," *Risk Analysis* 14, no. 2 (1994): 163–67.

13. Conversion efficiencies range from just around 5 percent for steam locomotives and 10 to 15 percent for poorly designed traditional stoves to 30 to 40 percent for better urban stoves and 50 percent for small boilers. In contrast, the best household natural gas furnaces have efficiencies in excess of 90 percent, as do the largest industrial boilers.

14. For comparison of recent air pollution levels in the world's largest cities, see Earthwatch, *Urban Air Pollution in Megacities of the World* (London: Blackwell Publishers and the World Health Organization, 1992).

15. Z. Dianwu and H. M. Seip, "Assessing Effects of Acid Deposition in Southwestern China Using the MAGIC Model," *Water, Air, and Soil Pollution* 60, no. 1 (1991): 83–97.

16. On indoor air pollution, see K. Smith and Y. Liu, "Indoor Air Pollution in Developing Countries," in J. M. Samet, ed., *Epidemiology of Lung Cancer* (New York: Marcel Dekker, 1994), 151–84. China is now the world's largest producer of cigarettes, and its total of 350 million smokers is growing by 2 percent a year. The average number of cigarettes smoked per day rose from 10 in 1994 to 14 in 1996. See *China News Digest*, Internet Files, 25 November 1996.

17. W. Jusi, "Water Pollution and Water Shortage Problems in China," *Journal of Applied Ecology* 26, no. 3 (1989): 851–57.

18. G. Dazhi et al., "Mercury Pollution and Control in China," *Journal of Environmental Sciences* 3 (1991): 105–11.

19. For details on nitrogen enrichment of the biosphere, see V. Smil, *Cycles of Life* (New York: Scientific American Library, 1997).

20. L. Bo et al., "Use of Night Soil in Agriculture and Fish Farming," *World Health Forum* 14 (1993): 67–70.

21. Recent benefit/cost studies of controlling air pollution in the Los Angeles basin are a perfect example. Total annual health benefits from reduced morbidity were found to be as low as $1.2 billion (1990 U.S. dollars), or as high as $20 billion. See A. J. Krupnick and P. R. Portney, "Controlling Urban Air Pollution: A Benefit-Cost Assessment," *Science* 252 (26 April 1991): 522–28; and J. V. Hall et al., "Valuing the Benefits of Clean Air," *Science* 255 (14 February 1992): 812–17. Given that it may take $13 billion (1990 dollars) to clean up the basin's air, morbidity costs alone can either easily justify the effort or make it economically quite unappealing.

22. For more on China's changing farmland, see F. W. Crook, "Underreporting of China's Cultivated Land Area: Implications for World Agricultural Trade," *China Agriculture and Trade Report* RS-93 (1993): 33–39; and V. Smil, "Who Will Feed China?," *The China Quarterly* 143 (1995): 801–13.

23. H. Chunru, "Recent Changes in the Rural Environment in China," *Journal of Applied Ecology* 26, no. 3 (1989): 803–12.

24. L.Yongzeng, "Chinese Forestry: Crisis and Options," *Liaowang* (Outlook) 12, no. 12 (December 1989): 9–10.

25. See, among many others, D. Heinsdijk, *Forest Assessment* (Wageningen: Center for Agricultural Publishing and Documentation, 1975); and R. Repetto et al., *Accounts Overdue: Natural Resource Depletion in Costa Rica* (Washington, D. C.: World Resources Institute, 1991).

26. Q. Geping and L. Jinchang, *Population & the Environment in China* (Boulder, Colo.: Lynne Rienner Publishers, 1994).

27. For more on noise in China's cities, see V. Smil, *Environmental Change as a Source of Conflict and Economic Losses in China* (Cambridge, Mass.: American Academy of Arts and Sciences, 1992).

28. World Bank, *Poverty Reduction and the World Bank: Progress and Challenges in the 1990s* (Washington, D.C., 1996).