Symposium:
China's Environment

Environmental Pollution in China: Status and Trends

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Introduction

According to official Chinese publications, China has made great progress in improving its environment. For example, the State of Environment (SOE) Report of 1998 states: "There has been continuing progress in the control of total amount of pollutants and industrial pollution sources and a comprehensive urban environmental improvement." According to the SOE of 2000, "Tremendous efforts have been made in abating environmental pollution, with a focus on water pollution prevention and control in key river basins, cities, regions and marine areas and industrial pollution control." The SOE 2006 offers a reassuring message: "Uniting all social forces and mobilizing the initiatives of each stakeholder, we have created a new situation where environmental protection is facilitated by all parties."

On the other hand, some researchers, commentators, and the media in the West paint a wholly negative picture. For example, Economy (2007) finds that "water pollution and water scarcity are burdening the economy, rising levels of air pollution are endangering the health of millions of Chinese, and much of the country's land is rapidly turning into desert." In late 2007, the *New York Times* ran a ten-part series titled "Choking on growth—Examining the impact of China's epic pollution crisis."

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Who is right? Is China's environment improving or worsening? This article, which is part of a three-article symposium on "China's Environment,"[1] attempts to answer this question. We provide a broad overview of the current status of China's environment, discuss recent trends in air and water pollution and China's contribution to global carbon dioxide (CO_2) emissions, and identify the main options for addressing the country's environmental problems. We find that there has been uneven progress in solving China's environmental problems. This may be due in part to the different policy options that are available for addressing, respectively, local, regional, and global problems. Our review also suggests that although China is starting from a point of grave pollution, it is setting priorities and making progress that resembles what occurred in industrialized countries during their earlier stages of development.

We start in the next section with a review of China's current environmental status. This is followed by a discussion of recent trends in China's local air and water quality, regional emissions and discharges, and contribution to global CO_2 emissions. The final section summarizes our findings and offers conclusions about the environmental path China has followed and its prospects.

The Current Status of China's Environment

Numerous reports have been published about the status of China's environment. For example, SOE reports are published annually by the Government of China, usually in connection with World Environment Day, June 5. International institutions such as the World Bank also publish state-of-environment assessments from time to time (e.g., World Bank 1997, 2001, 2007a, 2009), as does the research community (e.g., Liu and Diamond 2005).[2] This section discusses some of the main pollution problems identified in these and other reports.

Emissions to Air Are Very High

China has the dubious honor of being the world's biggest emitter of sulfur dioxide (SO_2). China's SO_2 emissions are almost as high as for Europe and the United States combined. China is probably also the world's biggest source of CO_2 emissions. The Netherlands Environmental Assessment Agency (2008) finds that China's CO_2 emissions were 14 percent higher than the United States's in 2007. It is not unlikely that China is also the biggest source of emissions of nitrogen oxides ($NO_x = NO + NO_2$). Official NO_x emission data are not published in China, but Zhang et al. (2007) estimate 18.6 million tons of NO_x in 2004, which is slightly higher than U.S. emissions of 17.7 million tons in the same year (USEPA 2007). However, China's per capita emissions of these compounds are much lower. CO_2 emissions per capita are still only 72nd in the world (WRI 2008) and only about a quarter of those in the United States. NO_x emissions per capita are also about a quarter of the United States's, while SO_2 emissions per capita are about half of the United States's.

[1]The article by Cao, Ho, and Jorgenson (2009) analyzes the costs and benefits of market-based policies (i.e., "green taxes") for controlling air pollution in China. The article by Cao, Garbaccio, and Ho (2009) examines the major policy measures being taken to reduce SO_2 emissions in China and assesses the benefits and costs of these policies.

[2]We are contributing authors to World Bank (2007a, 2009).

Data for some emissions may be understated. For example, Akimoto et al. (2006) recently compared observed concentrations of NO_x with coal consumption data published by the International Energy Agency (IEA) and China's National Bureau of Statistics (NBS). They found that both the IEA and NBS data understate coal consumption, and recommended that the coal consumption data not be used for NO_x emission inventories. Ohara et al. (2007) have developed an emission inventory for Asia and estimate that China's SO_2 emissions in 2003 were about 70 percent higher than officially reported. Moreover, current research at China's own Tsinghua University suggests that SO_2 emissions may be considerably higher than official figures (Zhao 2006).

The high SO_2 and NO_x emissions have serious implications. Both SO_2 and NO_x cause acid rain, and nitrogen compounds cause eutrophication (i.e., excessive fertilization of an ecosystem) (Gruber and Galloway 2008). At moderate concentration levels, NO_x emissions also contribute to formation of ground-level ozone. Both Aunan et al. (2000) and Wang et al. (2005) warn that ground-level ozone has already caused reductions in some crop yields. According to Aunan et al. (2000) the damage may become much more serious unless strong measures to reduce emissions are implemented. Ground-level ozone also causes damage to human health.

Ambient Air Quality in China's Cities Is among the Worst in the World

According to one study, twelve of the twenty most polluted cities in the world are located in China (World Bank 2007b).[3] This ranking is based on ambient concentrations of particulate matter less than 10 μm in diameter, PM_{10}. PM_{10}, and $PM_{2.5}$, which refers to even finer particles, are typically used in health damage assessments. PM has been singled out as the pollutant most responsible for the life-shortening effect of polluted air. PM_{10} concentrations are high in almost all Chinese cities. In fact, only 1 percent of the country's urban population lives in cities with an annual average level of PM_{10} that is below the European Union's air quality standard of 40 $\mu g/m^3$ (World Bank 2007a). The current annual mean guideline for PM_{10} given by the World Health Organization (WHO) is 20 $\mu g/m^3$ (WHO 2006).

More cities meet Chinese and Western air quality standards for SO_2. In 2003, for example, more than three-quarters of a sample of 341 Chinese cities had annual average SO_2 levels below 80 $\mu g/m^3$, which is the U.S. standard. On the other hand, the 24-hour guideline from WHO is as low as 20 $\mu g/m^3$.

Health Damages from Air Pollution Are Substantial

WHO has estimated that about 3.4 percent or three hundred thousand of the total deaths in China in 2001 were premature due to urban ambient air pollution (Zhang and Smith 2007). More recent research suggests that these figures may be even higher (World Bank 2007a,

[3]A popular, but unsubstantiated, media claim is that 16 of the 20 most polluted cities in the world are in China. This claim may be based on an earlier version of World Development Indicators (WDI). Sometimes the media report that Linfen, a city in Shanxi Province, is the most polluted city in the world. The reference to Linfen might be based on a ranking of Chinese cities that was reported in the Chinese media in 2004, http://www.chinadaily.com.cn/english/doc/2004–07/15/content_348570.htm. That ranking had nothing to do with the 16 out of 20, however.

2009). World Bank (2009) estimates that as much as 13 percent of all urban deaths may be premature due to ambient air pollution. Further, on an annual basis, the Bank finds that outdoor air pollution is responsible for two hundred seventy thousand (95 percent confidence interval: 240,000–310,000) cases of chronic bronchitis, and four hundred thousand (95 percent confidence interval: 210,000–560,000) hospital admissions from respiratory or cardiovascular disease. Between 5,000 and 6,000 man-years (8–9 million work days) are lost because of pollution-related hospital admissions. These estimates are based on monitoring data of varying quality combined with exposure–response functions derived from studies in limited areas of China or other countries. The underlying assumption that they are applicable to all of urban China entails uncertainties. Moreover, the estimates do not include the uncertainty in the population exposure assessment. Hence, the confidence intervals will in reality be considerably bigger than the nominal intervals given.

WHO estimates that indoor air pollution due to solid fuel burning shortens the lives of four hundred twenty thousand rural Chinese each year (Smith and Mehta 2003). Some researchers suspect that this number is far too low and that indoor air pollution is actually a more significant problem than outdoor air pollution. For instance, Mestl et al. (2007a) find that indoor air pollution shortens the lives of 3.1 million people in rural China annually. However, much research remains to be done to understand the impacts of indoor air pollution in rural China.

China's Rivers and Lakes Are Extremely Polluted

In the Huai river basin, one of the seven major river basins in China, it is currently recommended that humans avoid direct contact with water along 75 percent of river sections (by length) (SOE 2006). That is, these sections of the river are Class IV or worse according to China's surface water quality standard.[4] The figure is the same (i.e., 75 percent) for the Songhua river basin in the Northeast, while it is 80 percent for the Hai river basin surrounding Beijing. Rivers in the South, including the Yangtze, have better quality, but on average 60 percent of all rivers in China are Class IV or worse. The water in about half of this 60 percent is still allowed for use by industry and for irrigation.

China's major freshwater lakes are also extremely polluted, with the water in half of China's twenty-seven major lakes unsuitable for any use (SOE 2006). In three-quarters of China's lakes the water is Class IV or worse. In June 2007, Lake Taihu, China's third largest, experienced an environmental catastrophe when an explosive outburst of toxic cyanobacteria, commonly known as pond scum, colored the lake fluorescent green (e.g., Kahn 2007). Newspapers reported that the drinking water supply of two million people was disrupted for several days. This is despite the fact that the lake's water before the catastrophe was officially rated as unfit for human consumption.

[4]The Chinese standard distinguishes between five classes of surface water quality. Class I is reserved for headwaters and national reservation zones. Class II is suitable as so-called first-level drinking water reserves and habitat of precious aquatic life. Class III is acceptable for second-level drinking water reserves and swimming. Class IV is acceptable for industrial use, but direct contact with skin should be avoided. Class V, the most lax standard, is acceptable for irrigation only. Water that is worse than class V is unsuitable for all purposes.

Pollution Affects the Quality of Drinking Water and Enters the Food Chain

Despite the advice to avoid polluted water, several hundred million Chinese have no real alternative. Although the data vary, it is estimated that 300–500 million Chinese lack access to piped water. In addition, water pollutants reach the population through the food chain. Building on data from the Ministry of Water Resources in China, the World Bank (2007a) estimates that about 10 percent of China's water supply does not comply with the surface water quality standards. Most of this water is used for irrigation despite being worse than class V. China even has designated special wastewater irrigation zones, now totaling 4 million hectares, in which industrial wastewater or wastewater mixed with cleaner water is spread on the fields. The impact on crops is substantial. In the case of rice, for instance, about half of the yield fails to meet the Chinese standard for contamination. Mercury, cadmium, and lead are the primary pollutants found in rice (World Bank 2007a). Although it is difficult to establish a causal link, the rates of stomach and liver cancer are 50 percent higher in rural China than in the country's major cities (World Bank (2007a) citing Ministry of Health (2004)).

China Is Depleting Its Groundwater

The depletion of groundwater is also a growing concern. It is conventional to distinguish rechargeable shallow groundwater from nonrechargeable deep groundwater. Consuming deep groundwater is similar to mining a nonrenewable resource since exchange with surface water takes thousands of years. The World Bank (2007a), building on data from the Ministry of Water Resources in China, estimates that China consumes 25 billion cubic meters of deep groundwater annually. That is approximately ten times the total annual water consumption of Switzerland (OECD 2008). In some parts of the North China plain, the deep groundwater table has dropped more than 50 m since 1960, and it continues to drop 2 m annually (World Bank (2007a) citing Foster et al. (2004)). Huge drawn-down funnels under the ground have emerged in Northern and Eastern China. The funnel area of Hengshui and Cangzhou in Hebei Province is one of the largest, covering 9,000 square km (SOE 2006). Moreover, the land above some of the drawn-down funnels is sinking. Economy (2007) claims that land subsidence is threatening Beijing International Airport.

The Cost of Environmental Damages Is Estimated at 2–10 Percent of GDP

There have been many attempts to monetize the cost of environmental damages in China.[5] The World Bank (2007a, 2009) has carried out perhaps the most ambitious and current analysis in this regard. It incorporates recent exposure–response and willingness-to-pay (WTP) estimates, emphasizes studies on Chinese conditions, and builds on monitoring data that have recently become available. The World Bank (2009) estimates an environmental cost in 2003 of 300–1,300 billion RMByuan or 2–10 percent of 2003 GDP.[6] The range of

[5]See Panayotou and Zhang (2000) for a comprehensive review of such analyses. Of related interest is China's effort to develop a Green GDP. For the most recent published Green GDP (for 2004), which is based on methods developed jointly with the World Bank (2007a, 2009), see MEP and NBS (2006).

[6]At the time one USD was equal to 8.3 RMByuan. Hence, 300–1,300 billion RMByuan equaled 36–157 billion 2003 USD.

the estimate depends primarily on the valuation method and the number of excess cases of mortality and morbidity. The best estimate using the WTP approach to excess mortality and morbidity is 6.9 percent of GDP, while the best estimate using the human capital approach is 2.5 percent of GDP.[7] Unlike some previous efforts, World Bank (2009) includes impacts on mortality of long-term exposure to pollution. However, it does not include indoor air pollution, which, as noted above, is a serious problem. Nor does it include ground-level ozone, one of China's main emerging problems. The possible effects of acid rain on forests, also mentioned in some studies, are excluded because of uncertainty over the exposure–response function. Finally, well-documented environmental problems in China that are less directly related to pollution, such as degradation of land, ecosystems, and biodiversity (see, e.g., Liu and Diamond (2005) and World Bank (2001)), were deemed too complex to be quantified.

Environmental Damage Is Worse in the Industrialized Areas of Northern and Central China

With some exceptions, surface water pollution, groundwater depletion, wastewater irrigation, and consumption of noncompliant water are more serious problems in Northern and Central China than in the South. This is also the case for pollutants in rural drinking water, except for bacterial contamination. The main reason for the heavier pollution in Northern and Central China is the high industrial and agricultural activity and dense population. In Northern China the situation is also aggravated by low precipitation. Along the East–West dimension, problems are usually worse in the industrialized East.

Air pollution in urban areas is also generally worse in Northern and Central areas. PM_{10} levels of Northern cities are twice those of Southern cities (Fridley and Aden 2008), making the health impacts in the North more serious. Up to 20 percent of the population in the Northern provinces is expected to have shortened lifespans because of urban air pollution (World Bank 2009).

In rural areas, monitoring of air pollutants is still scarce. To get a sense of rural air pollution, the annual mean values for $PM_{2.5}$ were simulated using the global aerosol model Oslo CTM2 (Myhre et al. 2007) and data from Myhre et al. (2006, 2007) and Hoyle et al. (2007). The concentration levels of $PM_{2.5}$ on a regional scale (not including urban hot spots) were found to be especially high in North–West and Central China, at around 30 $\mu g/m^3$, but reached above 50 $\mu g/m^3$ in some areas. While the high levels in the North–West are mainly due to mineral dust (which may have a man-made component because of desertification), the high levels in Central China are mainly related to industrial and domestic coal combustion. Using a regional air quality model for China, Hao (2008) finds the situation to be even more severe, with values between 50 and 100 $\mu g/m^3$ in parts of Central China in the summer and reaching 150 $\mu g/m^3$ in large areas in the winter. For comparison, the WHO Air Quality Guideline for annual mean $PM_{2.5}$ is 10 $\mu g/m^3$ and the corresponding National Ambient Air Quality Standard in the United States is 15 $\mu g/m^3$.

[7] The human capital approach, which is popular in the Chinese research and policy community, equates a statistical life lost to discounted potential earnings lost by the deceased.

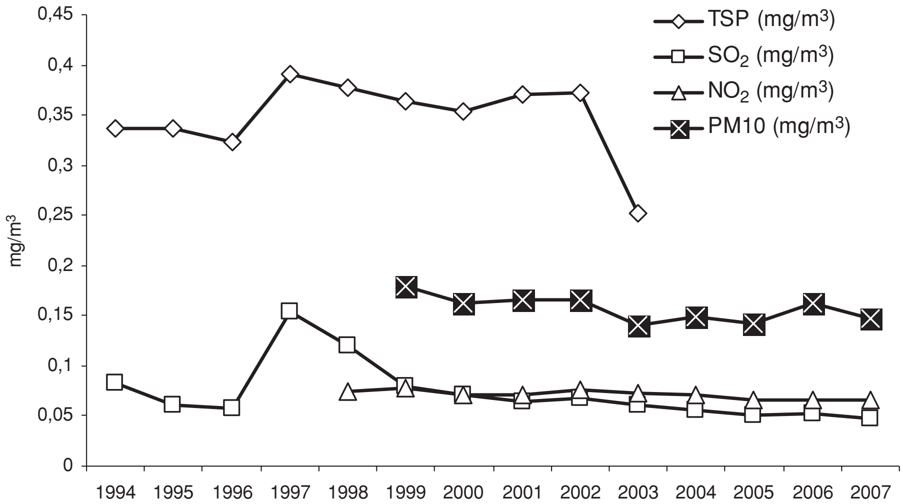

Figure 1. Air quality in Beijing.
Source: SOE (1995–2007).

Acid rain is predominantly a Southern phenomenon. In the North the natural dust contains basic components that neutralize acids formed from emissions of nitrogen oxides and sulfur oxides. Furthermore, soils and bedrock contain elements that could neutralize any acid deposition in the foreseeable future (Hicks et al. 2008). Another predominantly Southern phenomenon is indoor air pollution and the subsequent health damage (Mestl et al. 2007b).

Is the Environmental Situation Improving?

The bleak state of China's environment makes a strong impression on most observers. But the current situation might be easier to accept if things were changing for the better. Is that the case? In the next three sections, we survey trends in China with respect to local, regional, and global environmental problems. Local problems include problems at the village, city, and within-province level, such as local air quality and drinking water quality. Regional problems involve more than one province or neighboring countries, such as long-range transport of air pollution leading to acid rain, regional haze, and enhanced surface ozone levels or the water quality of China's major waterways. At the global level we examine trends in China's contribution to global CO_2 emissions.

Trends in Local Air and Water Quality

This section describes trends in local air quality, particularly in China's cities, and trends in the quality of the country's drinking water.

Local Air Quality in Cities

Monitoring data for many Chinese cities over the last decade show that air quality has been fairly stable. For example, as indicated in Figure 1, monitored air quality in Beijing shows no apparent change in particle and NO_2 concentrations, while SO_2 concentrations are trending downward.

The situation in Beijing is similar to other Chinese cities. Fridley and Aden (2008) present data for particle, SO_2, and NO_x air quality for about one hundred Chinese cities over a 25-year period (1980–2005) and find that a noticeable improvement in PM pollution took place during the 1980s and early 1990s. The average concentration of total suspended particles (TSP) halved between the 1980s and the early 1990s. Over the last decade there have been slight improvements for PM and for NO_x pollution. SO_2 levels have been relatively stable over the decade. The monitoring data for earlier years are particularly uncertain. Another difficulty is that the selection of cities varies. Still, the air quality data generally send the message that urban pollution is contained, and in some cases improved. The Ministry of Environmental Protection reports an overall improvement of urban air quality from 2006 to 2007 (MEP 2008).

The Chinese government's measure of air quality relies on what it calls an overall air pollution index.[8] According to this index, the picture is even brighter and the air quality in major cities is steadily improving. For example, between 2002 and 2007, a period during which energy consumption grew by 76 percent, the share of cities passing the class II air quality standard increased from 36 to 58 percent. Andrews (2008) criticizes the government's air quality index for Beijing as presenting an overly optimistic picture.

As we shall see in the next section, the cited improvements in local air quality do not necessarily concur with the trend in emissions in China. One of the challenges is to understand why this happens. Which strategy does China follow to prevent higher emissions from causing a deterioration in air quality levels? An obvious strategy, known from Western countries during the last century, is to move pollution sources out of city centers and build higher stacks so that emission is dispersed and diluted. This seems to be the strategy that China is following now.

To illustrate this point let's return to the example of Beijing. To be sure the city must fight off pressures that, by themselves, worsen air quality. One much publicized statistic is that every day brings one thousand two hundred additional motor vehicles onto the roads of Beijing (NBS 2006, 2007). To address this and other pressures the city government has begun to close down heavy industry located in the center. For 85 years, the Capital Steel Group (Shougang), China's fourth largest steelmaker by output, was located in the middle of Beijing. Capital Steel is now moving out to locations in neighboring Hebei Province, a process that will be completed by 2012. A coking plant, Beijing Coking and Chemical Works, stopped production in 2006. The city of Beijing is also cleaning up emissions from its five power plants and has adopted Euro IV vehicle emission standards.[9]

Although the 2008 Olympics gave Beijing a special incentive to clean up, city governments across China are acting in a similar fashion. For example, between 1990 and 2005, the percentage of urban households with access to gas has increased from 19 percent to 82 percent. Access to gas has eliminated the direct burning of coal for cooking and heating in millions of urban households. In addition, small low-stack boilers have been replaced with

[8]For a detailed description of this index and its complicated structure, see http://www.sepa.gov.cn/quality/background.php. In practice PM is often the main determinant of the index.

[9]Euro IV is an emission standard for heavy-duty vehicles adopted in Europe. There are corresponding emission standards for light-duty vehicles.

large, efficient high-stack district heating plants. The city initiatives help to reduce emissions from the cities themselves, although some of them simply move emissions out of town, just as emissions moved out of European and U.S. cities several decades ago.

Drinking Water Quality

Although the condition of surface water in China is extremely poor, it is difficult to determine the extent of damage it does to humans, since families and households have ways to avoid drinking polluted water. Access to tap water has improved significantly among urban Chinese households, from 48 percent in 1990 to 91 percent in 2005 (NBS 2007).[10] Official Chinese data for the rural population, which accounts for 55 percent of the total, are sparse. According to the *China National Health Survey*, cited in World Bank (2007a), 34 percent of the rural population had piped water in 2003.[11] Comparable figures for earlier years are difficult to obtain, but estimates in WHO-UNICEF (2004) indicate only a modest improvement since 1990.

WHO-UNICEF (2006) estimates that access to improved sanitation among rural households, including flush, biogas facility, and deep pit toilets, increased from 7 percent in 1990 to 28 percent in 2004.

Improved sanitation, along with improved hygiene and other interventions, has allowed China to greatly reduce the incidence of some diseases typically associated with water-borne fecal contamination. For instance, the incidence rate for dysentery in 2003 was less than one-sixth of the rate 20 years earlier, with the greatest decline occurring before 1990 (Ministry of Health 2004).

Trends in Regional Emissions and Discharges

Although measures can be taken to relocate and disperse emissions, large emissions of SO_2, particles, and NO_x will contribute to regional problems. Likewise, allowing water bodies to stay polluted entails large costs related to drinking water treatment and measures to avoid exposure for those who can afford it—and health damage for those who cannot. This section discusses recent trends in regional emissions of SO_2, PM, and NO_x and trends in regional water quality.

SO_2 Emissions

China is paying close attention to reducing SO_2 emissions. The government has designated control zones for SO_2 and acid rain, and developed a battery of policies and regulations to control SO_2 emissions (see, e.g., Cao, Garbaccio, and Ho (2009), in this symposium). The policies range from economic incentives such as a nationwide SO_2 emission levy to

[10]The definition of urban population here is permanent residents of city districts. Data from 2006 and 2007 are published, but are not directly comparable since they also include temporary residents. As a result the urban population has swelled and the measured access rate to tap water decreased to 87 percent in 2006. (Similarly for gas, the rate dropped from 82 to 79 percent.)

[11]The 3rd National Health Service Survey is a household-level survey covering about 195,000 households in 95 counties across China.

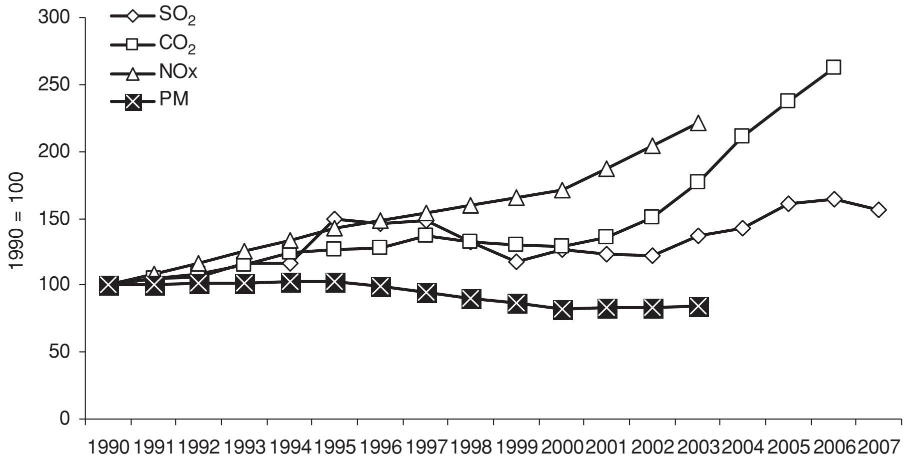

Figure 2. Emissions of SO_2, CO_2, NO_x, and PM relative to 1990.
Notes: PM refers to carbonaceous particles (the sum of black carbon and organic carbon) and does not include open biomass burning.
Sources: For CO_2 data, see Figure 4. SO_2 data are from Larssen et al. (2006) for 1990–1994 and from SOE (various years) for 1995–2007. NO_x and PM data are from Ohara et al. (2007).

requirements for SO_2-abatement technology in power plants of a particular age and size. The macro-level goal is to reduce SO_2 emissions to 22.9 million tons in 2010. So far China has struggled to achieve this goal. However, according to MEP (2008), SO_2 emissions were reduced from 25.9 million tons in 2006 to 24.7 million tons in 2007.

As Figure 2 reveals, the increase in SO_2 emissions is lower than the increase in CO_2 emissions over the (fairly) long run. This in practice implies that the macro emission factor (SO_2/fossil energy) is falling. Our data suggest that on average the emission factor has been falling 2 percent annually since 1990, and it is evident that it has fallen more in recent years.[12]

Using provincial data for the period 1993–2002, Shen (2006) finds that the factors determining SO_2 emissions include the share of manufacturing industry in the economy, abatement expenses, population density, and a strong positive time trend. Per capita GDP is negatively correlated with SO_2 when it is below 5,300 (1993) RMByuan (about 640 (1993) USD), but it is positively correlated at per capita GDP levels above 5,300 (1993) RMByuan. In other words, Shen (2006) finds a U-shaped association with GDP per capita rather than the bell-shaped (inverted-U) association, referred to as the "Environmental Kuznets Curve," demonstrated in several settings (see, e.g., Grossman and Kruger 1995). Since GDP per capita is increasing over time, this result does not bode well for China's SO_2 emissions unless more emphasis is placed on abatement. However, as noted previously, the data from the period 1993–2002 are uncertain.

[12]We must remind readers about the uncertain quality of Chinese energy and environmental data overall, including SO_2 data. For example, MEP and NBS (the statistics bureau) have published conflicting SO_2 emission data for the 1990s. NBS (2004) includes revised SO_2 emission data from 1999 onward. Thus, the data for SO_2 emissions since 1999 are probably of better quality than earlier data. The spike in emissions in 1995 is probably due to the inclusion, from that year, of emissions from town and village enterprises (Fridley and Aden 2008).

Household Sector Emissions

Some additional insights about trends in SO_2 emissions can be gathered by examining the data from NBS for various years. These data show that SO_2 emissions are growing more slowly than CO_2 emissions because of lower SO_2 emissions from what are referred to as "households and other sources." Published household emissions were 5.0 million tons in 1997, but had declined to 3.6 million tons by 2006. It seems clear that China is making progress in reducing household emissions in most urban areas. This is because liquefied petroleum gas (LPG), as well as natural gas and town gas made from coking coal, is replacing individual coal consumption. In addition, district heating is being modernized, which is reducing energy consumption and SO_2 emissions (Mestl et al. 2005). While households' consumption of coal in urban areas is falling, the trend in rural areas is not clear (Streets and Aunan 2005). However, the main challenge for reducing SO_2 emissions now lies with the industry and power sector, whose emissions have increased until now.

Industry and Power Sector Emissions

One example of the challenge associated with reducing SO_2 emissions from industry and power plants in China is the case of flue gas desulfurization (FGD). FGD is a simple end-of-pipe intervention that reduces SO_2 emissions from power plants by 90–95 percent if correctly installed and operated. In other words, if implemented throughout China, FGD would basically solve the problem of SO_2 emissions from power plants and some industry. The typical cost of a Chinese-designed FGD unit for a power plant is 300–500 RMByuan per kW ($40–$65 per kW) (see, e.g., Zhang 2005). This is lower than the cost of Western designs and would add about 5–10 percent to power plant costs. FGD also requires lime and other substances for operation, and it lowers energy output by 1–2 percent.

Despite the obvious benefits of FGD, China has struggled to install FGD units in its power plants. Although the government tripled the SO_2 emission levy from 0.2 RMByuan/kg to 0.63 RMByuan/kg in the 10th five-year plan (2001–2005), it had only limited success.[13] FGD penetration increased from 2 percent in 2000 to 14 percent by the end of 2005 (NDRC 2006a). The 11th five-year plan (2006–2011) includes additional policies. These comprise stricter emission standards that can barely be met without FGDs, and a subsidy of 0.015 RMByuan/kWh to power plants with FGD (NDRC 2006b). These recent policies seem to have worked, as more than half of China's power plants are now reported to have FGD in place (MEP 2008).

In order to effectively control SO_2 emissions, FGD units that have been installed must also be operated. Unfortunately, the most recent information indicates that almost half of the FGD facilities are lying idle (NDRC 2006a; Fang 2008). Why are these facilities not in use? One factor is the cost of operation, which is reportedly higher than the pollution levy.[14] A second factor is that Chinese power producers are currently under pressure to cut costs. They

[13]The Chinese experience with pollution levies is reviewed in Jiang and McKibbin (2002) and Wang and Wheeler (2005). They find that levies have had an effect on emissions and water discharges despite criticism that levies have been too low.

[14]Zhang (2005) estimates the operation and maintenance cost of FGD facilities at 0.75 RMByuan/kg, compared to the levy of 0.63 RMByuan/kg.

cut costs because although the price of coal in China has increased significantly in recent years, the price of power is regulated and has not been allowed to increase as much. The pressure to cut costs gives power producers an incentive to bypass operation of the FGD. The pressure to cut costs also encourages power producers to purchase cheap, low-quality coal that is high in sulfur content, which of course only adds to the SO_2 emission problem.

The case of FGD illustrates some of the challenges of controlling SO_2 emissions in China. Ambitious policy targets will remain unfulfilled unless economic incentives are provided or there is stricter monitoring and enforcement of policies. Since FGDs and other abatement devices are not profitable investments for power plants, until now they have not been emphasized in practice. On the other hand, a domestic industry has finally emerged that supplies FGDs at prices below international competitors and economic incentives are stronger than before. Thus the present problem of not operating FGD equipment that has been installed is in our view likely to be temporary.

PM and NO_x Emissions

Time series data for total PM emissions in China are scarce and not reported by MEP. However, Ohara et al. (2007) report that Chinese emissions of PM in the form of carbonaceous aerosols were reduced by about 15 percent in the period 1990–2003, from 4.5 million to 3.8 million tons per year (see Figure 2).[15] One reason for the decline in PM is decreased consumption of coal by households, which, as noted above, also lowers SO_2 emissions and air pollution concentrations. Another reason is the gradual installation of electrostatic precipitators (ESPs), and fabric filters to a lesser extent, in power plants and major industrial facilities. The ESP has an abatement efficiency of 97–99.5 percent, a drastic improvement over previous technologies.

Concerning NO_x emissions, Richter et al. (2005) found that NO_2 concentrations increased by about 45 percent over Central China from 1996 to 2002. Ohara et al. (2007) estimated that NO_x emissions increased by 28 percent during the same period (see Figure 2) and that from 1980 to 2003 NO_x emissions increased by a factor of 3.8. Their estimate for 2003 is 14.5 million tons of NO_x. Zhang et al. (2007) estimated that NO_x emissions rose from 10.9 million tons in 1995 to 18.6 million tons in 2004. If China follows the same policy path as Western countries, more focus on nitrogen oxide compounds can be expected in the future.

Water Quality of Rivers

The water quality of China's rivers represents a regional environmental problem because rivers may run through several provinces. This means that the development and implementation of policies to improve water quality requires interprovincial cooperation, which is part of the reason why the environmental quality of China's rivers is low.

Yet China has made some progress in this area. According to data from China's MEP (SOE 2002–2007), the share of surface water in China's seven major river basins that is at or better than Grade III—which means it can be used as a drinking water source—is

[15] Carbonaceous aerosols, the sum of black carbon (BC) and organic carbon (OC), are a subfraction of $PM_{2.5}$. Again, there are large uncertainties in the data. For instance, the estimates provided by IIASA (2008) for emissions of BC and OC in 2000 are approximately twice as high as the estimates in Ohara et al. (2007).

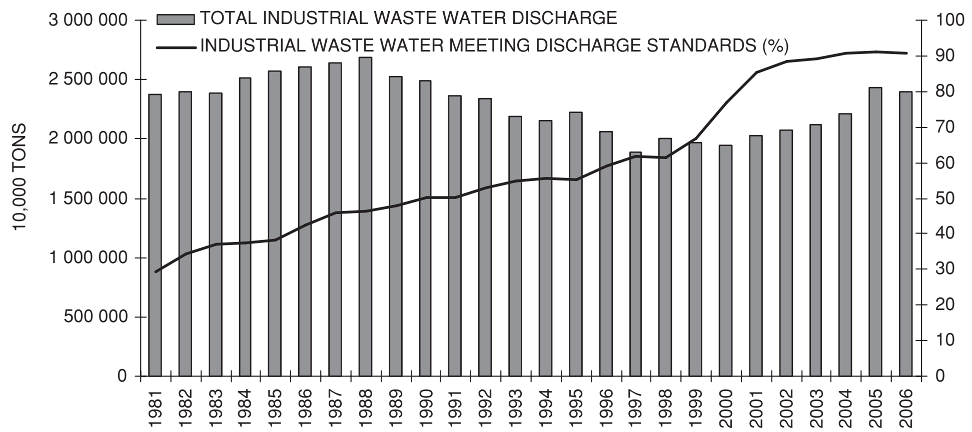

Figure 3. Discharge of industrial wastewater in China.
Source: NBS.

slowly increasing and has surpassed 40 percent. A few years ago the share was only 30 percent. One explanation for the improvement is that more industrial wastewater is being treated and is meeting discharge standards (see Figure 3). The share that is treated and meeting standards has reached 90 percent. Urban sewage treatment is also increasing steadily and reached 46 percent in 2004 (World Bank 2007a). However, due to rapid urbanization, untreated discharges from urban households were still increasing in the period 2001–2005 (MEP 2006).

Most of the improvement in water quality has occurred in the Southern river basins, which had the best quality to begin with (World Bank 2007a). It has also been claimed that MEP now monitors more upstream locations than before, including more natural reserves and naturally clean sections (Roumasset, Wang, and Burnett 2008). This of course would also result in improvements in measured water quality.

Industrial wastewater is probably the biggest success story among China's major discharge and emission categories. Industrial chemical oxygen demand (COD) discharge fell 18 percent during the 10th five-year plan (2001–2005). According to MEP (2008), COD discharge across China was about 3 percent lower in 2007 than in 2006. Industrial ammonia nitrogen emissions fell 25 percent during the 10th five-year plan.

Nonpoint sources (i.e., small and diffuse sources) are difficult to monitor and control. Agricultural runoff is the single largest contributor, with increasing values of inorganic N (nitrate + nitrite) reported in large parts of the country. The sources are probably mainly fertilizers and animal waste (UNEP/GEMS 2006). The East China Sea is becoming more affected by inorganic N from agriculture in the sea's catchment area. This has resulted in increased frequency of algal blooms (UNEP/GIWA 2006). On the positive side, concentrations of some pesticides (e.g., technical hexachlorocyclohexane) decreased to very low levels in the early 1990s (UNEP/GEMS 2007).

At least two recent papers have attempted a systematic panel data econometric review of China's water discharges. Both Shen (2006) and De Groot, Withagen, and Zhou (2004) have found that China is making progress in controlling wastewater pollution over time and as GDP grows. However, the data do not include the most recent years and their models explain only a small share of the variation in the data.

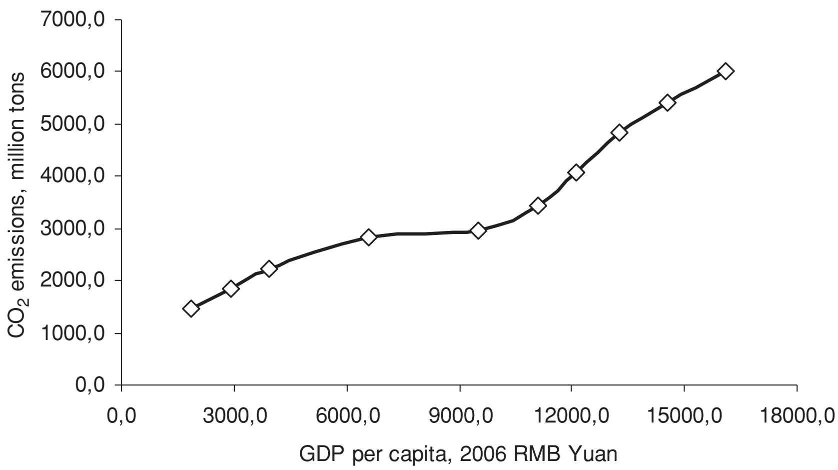

Figure 4. CO_2 emissions and GDP per capita, 1980–2006.
Sources: GDP data are from NBS (2007). CO_2 data are from the US Department of Energy (EIA 2008) with 2006 as the final data point There are several sources providing CO_2 estimates for China. IEA (2008) provides data via a Reference and Sectoral Approach that also have 2006 as the final data point. WRI (2008) and Marland, Boden and Andres (2008) provide alternative estimates, which at the time of writing stop in 2005. The estimates are close, but not identical, to the two IEA data sets, which are about six percent lower than the others. The Netherlands Environmental Assessment Agency (2008) also provides an estimate. Their estimate is the same as WRI up to and including 2005, while their 2006 estimate is four percent higher than the EIA estimate that we use here. The Netherlands Environmental Assessment Agency is the only institution to provide a 2007 estimate, eight percent higher than their 2006 estimate.

Trends in CO_2 Emissions

As mentioned in the Introduction, China is likely the world's biggest source of CO_2 emissions and is #72 in terms of CO_2 per capita. The trend in CO_2 emissions in China is shown in Figure 2 and an accelerating path is apparent. Such a time trend is not very informative by itself, particularly since GDP is also accelerating. In Figure 4 we plot CO_2 emissions relative to GDP per capita and observe a macro relationship that is roughly linear. A concave tendency from approximately 4,000 to 9,000 RMByuan is later replaced by a convex tendency from 9,000 to 12,000 RMByuan. Most recently, above 12,000 RMByuan there might be a second concave phase, but the overall impression is that of linearity.

A linear macro relationship between GDP per capita and CO_2 emissions implies that to produce an additional RMByuan of income per capita the economy requires a constant increase in CO_2 emissions. This is a quite strong prediction since both energy efficiency improvements during growth, and structural adjustment toward light industry and services during growth, would produce a concave curve whereby each new RMByuan of income is associated with slightly lower CO_2 emissions than the preceding one. In other words, a concave shape is what one normally would expect. In China, the concave phase seems to have been reversed. For instance, energy consumption increased 60 percent in just four years, 2002–2006 (NBS 2007). During the same period economic growth was also high (50 percent), but lower than energy consumption. It is this reversal of earlier trends that has led to surprisingly high growth in CO_2 since the turn of the century. The question is why?

First we confirm that the crude impression in Figure 4 holds up to scientific scrutiny. Auffhammer and Carson (2008) use provincial data from 1985–2004 plus an estimate of the mass of CO_2 emissions from the volume of waste gas emissions to produce a forecasting model for Chinese CO_2 emissions. Their preferred models, which depend on income and provincial lagged emissions, indicate that future Chinese CO_2 emissions will be considerably higher than anticipated at the turn of the century. At that time, GDP per capita stood at 9500 (2006) RMByuan. In terms of Figure 4, one was at the end of the concave phase of the relationship. The higher emissions forecasted now probably have a counterpart in the subsequent convex phase of the macro relationship. Auffhammer and Carson (2008) reject the Environmental Kuznets Curve specification, which is an extreme form of a concave relationship.

In another careful contribution Peters et al. (2007) use industry fuel and process data from 1992–2002 in combination with IPCC default emission factors to construct a 95-industry CO_2 emission inventory for the period. Using detailed input–output decomposition, they ask which final demand categories are driving the growth in China's CO_2 emissions. They find that emissions are primarily driven by capital investment and by the growth in urban consumption. Both these demand categories have been booming in recent years, consistent with the convex portion of Figure 4. Peters et al. (2007) also find that energy efficiency improvements offset about half of the CO_2 increase that would have followed from a pure scaling up of the 1992 economy to 2002. In fact, with energy efficiency improvements, the CO_2/GDP ratio in 2002 was about one-third of what it was in 1980 (cf. Raupach et al. 2007). These findings explain the concave part of Figure 4. After 2002 the ratio increases slightly until it seems to go down slightly in 2007.

Let us turn now to the question of whether structural change or a halt in energy efficiency improvements is to blame for the increase in China's CO_2 emissions. Lin et al. (2008) are among the many who suggest that the main cause of the increase in CO_2 emissions is that energy efficiency in individual industries cannot offset the effect of structural change on CO_2 emissions, particularly the rapid increase in production of energy-intensive products such as iron, steel, and cement. For instance, production of cement increased by 70 percent in the four years from 2002 to 2006, and production of rolled steel increased by almost 140 percent. Overall, in the period 2001–2006, the industrial share of GDP grew by 3.8 percent, while shares of primary and tertiary industries both declined (NBS 2007). There are signs, however, that this shift toward energy-intensive products is losing momentum. For example, while the annual growth in coal use was on average 16 percent in the period 2001–2006, the growth slowed to about 8 percent in 2007 (BP 2008). In late 2008, the downturn of the global economy hit China, with major producers announcing 20 percent cuts in steel production (*China Daily* 2008).

Accepting that structural change is to blame, the next question is why has there been such a negative (for the environment) structural change? We believe the answer here lies in the desire to achieve economic growth. Economic growth in China has always been driven by investment, a trend that has become even stronger in recent years. This investment is financed by the country's huge savings, which to a large extent result from industries' habit of reinvesting profits (e.g., He and Kuijs 2007). Reinvesting profits has historically been encouraged by government officials whose job evaluation depends on local economic growth (Li and Zhou 2005). Governments and households have played a role in investment and stimulating growth too, with governments favoring infrastructure investments and households investing heavily in housing following the liberalization of the housing market in the late 1990s.

In summary, an important driver for higher CO_2 emissions is the desire for economic growth, which combines with other drivers such as housing demand to form a high rate of savings and investment. High investment results in high construction activity and high growth in heavy industries. These industries are the heavy energy consumers and polluters.

An additional reason for the excessive growth in energy consumption may simply be that energy consumption and production were underreported in the five years prior to 2002. IEA (2007) discusses the quality of Chinese energy statistics and points out the huge imbalances between production data and consumption and trade data, especially historically. Akimoto et al. (2006) note that coal consumption in 2000, measured as the sum of provincial figures and reported by China's national statistical yearbook, was 50 percent higher than the national total reported by the same yearbook. The national figure has since been revised. Another reason for the growth in energy consumption is that the expansion of the energy system had not kept up with economic growth in previous years, which led to power shortages around 2003. Thus the energy system needed to grow to eliminate these shortages.

One glimmer of hope from an environmental perspective is that the Chinese economy can hardly become more resource intensive than it is now. Compared to other countries at a similar level of development, China relies on manufacturing industry to an unusually great extent. For example, the industrial share of GDP in China is almost twice the share in India, a much poorer country, and the share devoted to service industries is lower in China than in India (Felipe et al. 2008). World Bank and Chinese researchers point to the need to "rebalance" the economy (He and Kuijs 2007). In fact, China's leadership has changed the incentives for provincial leaders and leaders of key enterprises from only encouraging economic growth to also encouraging energy conservation and reduction of emissions of major pollutants (e.g., State Council 2008).

Another promising development is that energy efficiency improvements, clean coal strategies, and renewable energy policies have become important elements in Chinese policies, reflected in a range of recent laws and regulations (e.g., Aunan et al. 2006). One reason behind this is an increasing concern for energy security, but considerations of climate change are also involved to some extent (e.g., Richerzhagen and Scholz 2008). By some accounts, China is home to half of the world's Clean Development Mechanism (CDM) potential (World Bank 2004), and in 2007 70 percent of the total contracted CDM volume in the world came from China (Point Carbon 2007).[16] Moreover, awareness of the potential negative impacts of climate change on China appears to be increasing, as shown, for example, in the report "China's National Climate Change Programme" (NDRC 2007), which summarizes the alarming potential impacts of climate change on water scarcity.

It is also becoming increasingly clear that China has a pool of cost-effective technical interventions to reduce CO_2. The pool may be as large as 30 percent of baseline emissions (see, e.g., Aunan et al. 2006, 2007; Vennemo et al. 2009). Some of the interventions are

[16]CDM is a mechanism that allows countries committed to greenhouse gas reductions under the Kyoto protocol to fulfill some of their commitment through reductions in non-committed countries. In practice, the CDM allows developed countries to finance greenhouse gas reduction projects in developing countries.

financially profitable, while others offer local- and regional-level environmental benefits that are greater than the costs. Sooner or later China will begin tapping into this pool of cost-effective interventions, which will contribute to lower CO_2 emissions.

Summary and Conclusions

This article has documented that the current state of China's environment is bleak. Yet we have also argued that progress has been made with respect to *local* pollution problems, particularly in urban areas. For instance, access to safe drinking water is increasing and urban air quality is stable. We see scattered progress with respect to some *regional* pollution problems. For instance, the surface water quality of China's major river basins seems to be improving slightly, although the improvement has mostly been limited to the Southern river basins. SO_2 emissions to air increased in the early part of the decade, but emissions may have flattened out or even be decreasing. Emissions of NO_x are rapidly increasing but emissions of PM are fairly stable. While emissions of PM, NO_x, and SO_2 to air are contributing to deteriorating regional air quality, the technologies needed to reduce industrial and power emissions are available and some of them are being implemented, which holds promise for the future. There has recently been little progress in controlling emissions of CO_2, the most serious *global* environmental problem. Although there is some commitment to promoting energy efficiency and renewable energy, two important avenues for CO_2 control, on balance recent development trends in China have aggravated the CO_2 emission problem. The current, unfolding macroeconomic downturn may in the short run contribute to lower Chinese CO_2 emissions. In the longer term, the downturn presents both opportunities and threats to efforts to control CO_2 emissions in China as in other countries.

Solving local environmental problems often yields large short-term benefits relative to cost. Some options exclusive to local problems, such as extending the height of stacks, moving polluting industries out of town, and building a drinking water treatment plant, are low-cost and have an immediate impact on local pollution levels, health, and comfort. This implies a high benefit–cost ratio. These options can also be implemented locally, without the need for regional cooperation. These factors may explain China's emphasis on local environmental problems.

An important issue is where China is heading with respect to its regional pollution problems. Here we are cautious optimists. With local problems under control, rising affluence, and improved technologies, a nation typically starts paying attention to regional problems. Compared to local problems, solving regional problems requires a higher degree of institutional capacity and collaboration. But technically it is relatively straightforward to clean up rivers and improve regional air quality. The experience from industrialized countries indicates that there will be progress over time, although NO_x emissions remain a difficult problem, even in industrialized countries. Given China's high savings rate, the financial resources are available for reducing regional pollution problems if the necessary political will can be mustered. The economic downturn may in the short run reduce financial flexibility, however.

Helping to address the global issue of CO_2 emissions is a much more difficult problem for China. However, research indicates that large emission savings can be achieved as a by-product of addressing local and regional problems. Moreover, over time, China's industrial structure is likely to become more environmentally friendly.

China's development with respect to environmental pollution appears to be following a path that is similar to the one established by more industrialized countries when they were at earlier stages of development. Global financial institutions and the donor community, as well as many ordinary citizens in industrialized countries, are urging that China should do better than that, and possibly "cut the Environmental Kuznets Curve" (i.e., avoid the peak in environmental damage). To some extent the European and U.S. judgment of China's environment is biased by the post-pollution preferences of people currently living in these regions. But there is also a concern that China does not make the same mistakes that Western countries acknowledge that they themselves made in the past. The epidemiological and environmental economic evidence clearly indicates that rapid environmental improvement in China will save thousands of lives and easily pass benefit–cost tests. Moreover, it is clear that at least in some areas abatement technologies are now relatively cheaper than when Europe, the United States, and Japan tackled similar problems. On the other hand, China is more reliant on heavy industry than other countries at a similar stage of development. Although we are convinced that China will make progress in addressing its environmental issues and problems, it remains an open question whether China will progress faster on the environment than its industrial country predecessors.

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