Is China's Growth Sustainable?

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Abstract

A central pillar of the sustainability movement is the call to include environmental accounting in standard measures of economic performance. This increased transparency would, in principle, mitigate the temptation of economic managers and policy makers to increase growth in material consumption at the expense of the environment. Moreover, as Repetto (1989) and others have argued, deducting depreciation of produced capital from NNP but not deducting depreciation of natural capital is inconsistent and debases NNP as a possible indicator of welfare. Based on the evidence available, it appears that while GNNP is substantially less than NNP, these adjustments do not adversely compromise existing estimates of economic growth for China.

JEL classification: O13, Q01, Q2, Q3, Q4, Q5

Keywords: sustainable development, China, genuine saving, SOx, NOx, TSP, resource depletion, natural capital, Environmental Kuznets Curve, green net national product

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INTRODUCTION

This paper assesses the nature and degree of environmental degradation and resource depletion in China and their relationship to economic activity and environmental policies. We describe regulatory and other policies and consider their political economy determinants. Inasmuch as this objective can only be partially achieved, we hope to contribute to a research agenda for environmental and resource economics in China.

Claims have been made that the damage to China's environment is significant and has had a negative influence on economic growth. Critics argue that uncontrolled waste of resources and environmental degradation have offset much of China's economic growth over the past twenty-five years. Accordingly, a secondary objective of this chapter is to address whether environmentally augmented accounting substantially reduces the magnitude of China's economic gains.

We begin by reviewing evidence on air and water pollution, including environmental Kuznets curves (EKCs) for three major air pollutants, in the "Pollution" section. The section on "Natural Capital" follows with an overview of the country's natural resources, and how their quality and quantity have changed over time. In the "Natural Resources Kuznets Curve" section, we develop a theory regarding a country's *natural resource Kuznets curve* and apply it to empirical data on the value of China's natural resource degradation over a thirty-year period. To formally address the question of China's growth rate, we extend green accounting theory to facilitate a comparison of conventionally measured net national product (NNP) and *green* NNP (GNNP). The section on “Green Net National Product” provides a discussion of forces that cause GNNP to grow at first more slowly but then faster than NNP. Available estimates of China’s GNNP conform to these predictions. An indicator of sustainability similar to genuine saving, termed *genuine capital accumulation* (GKA), is shown to be dramatically increasing in the “Genuine Capital Accumulation” section. The section on “Policy Environment” reviews the current policy environment, emphasizing both accomplishments and shortcomings, and the last section concludes.

POLLUTION

Air Pollution

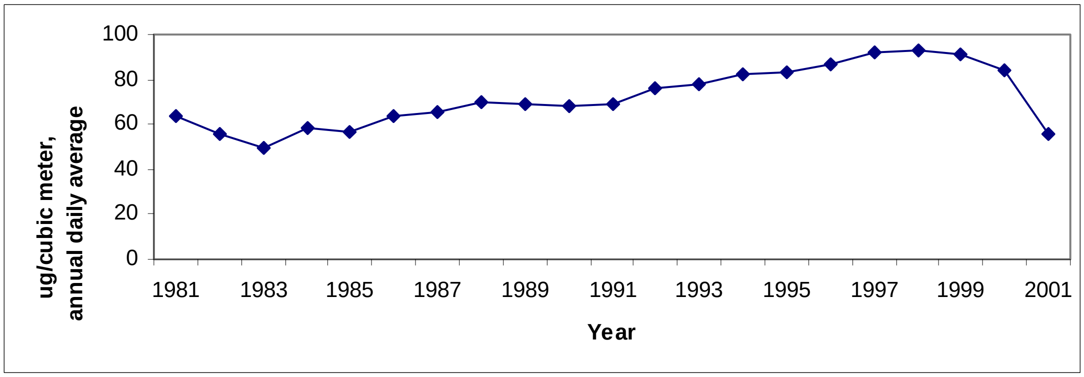
Currently, the three air pollutants of concern are sulfur dioxide (SO_2) from the burning of coal for power generation; nitrous oxides (NO_x), mainly from motor vehicle emissions; and total suspended particles (TSP) due in part to the growing desertification of the Northwest and energy consumption in the South. Due to China’s dependence on coal (68 percent of energy consumption), windblown SO_2 emissions from China may account for more than 13 percent of sulfur deposits in South Korea and up to 50 percent in Japan (Wishnick, 2005). Higher incomes have led to increased car ownership (although this is still less than 2 percent), and motor vehicles account for 45–60 percent of NO_x emissions and 85 percent of CO_2

emissions in cities (Wishnick, 2005). One-third of China's total land area is prone to desertification, including 262 million hectares of pastoral and oasis land in the Xinjiang, Inner Mongolia, Tibet, Gansu, and Qinghai provinces.

Air pollution is a major health issue. Ambient and indoor air pollution has been blamed for the high incidence of premature deaths (World Bank, 1997). Particulate matter with a diameter less than 10 microns (PM-10) is the most damaging air pollutant in terms of health costs. In 2002, China's State Environmental Protection Agency (SEPA) tested the air quality in over 300 cities and found that two-thirds did not meet standards set by the World Health Organization (WHO) for acceptable levels of TSP (Economy, 2004). In 1995, the World Bank estimated that health damages due to air pollution accounted for 7.1 percent of national income (World Bank, 1995). This estimate may be inflated, however, inasmuch as the methodology infers the value of life in China from U.S. estimates, without accounting for the extent of overpopulation (see, e.g., Dasgupta, 1993, 2001).

A recent report from the State Environmental Protection Administration (SEPA, 2004) asserts that either air pollution in major cities has been improving or the speed of deterioration has decreased, with falling emission levels and improved efficiency in plants. Total levels of NO_x, as shown in Figure 1, have fallen recently. Statistics show that SO_2 and TSP have been declining in the major cities since the mid-1980s, as shown in Figures 2 and 3. These figures represent ambient concentrations of the three major pollutants for eleven of China's major cities.[1] With China's rapid development, a natural question arises regarding how these levels have fallen given increased production and economic output over this same period. For example, SEPA asserts that in 2002, national environmental quality was maintained at the level of the previous year, while the national gross domestic product (GDP) grew by 8 percent. Furthermore, SEPA (2004) reports reduced levels of dust and sulfur dioxide, stable water quality, and improved air quality in many cities.

Figure 1. Ambient NO_x Concentrations in Eleven Chinese Cities, 1981–2001



(*Note*: The observations are population-weighted averages of data for individual cities. *Source*: Ambient concentration data: World Bank's Development Research Group (DRG); population data: http://www.citypopulation.de/China.html.)

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[1] The sample cities are as follows: Tianjin, Guangzhou, Beijing, Shanghai, Chengdu, Changchun, Taiyuan, Anshan, Nanchang, Shenzhen, Yinchuan, and Guilin (chosen for their completeness of data).

Figure 2. Ambient SO_2 Concentrations in Eleven Chinese Cities, 1981–2001

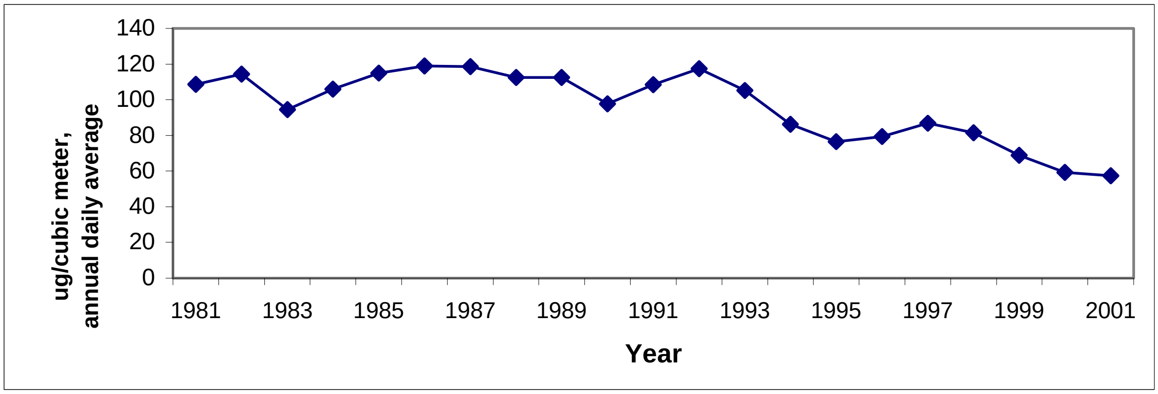
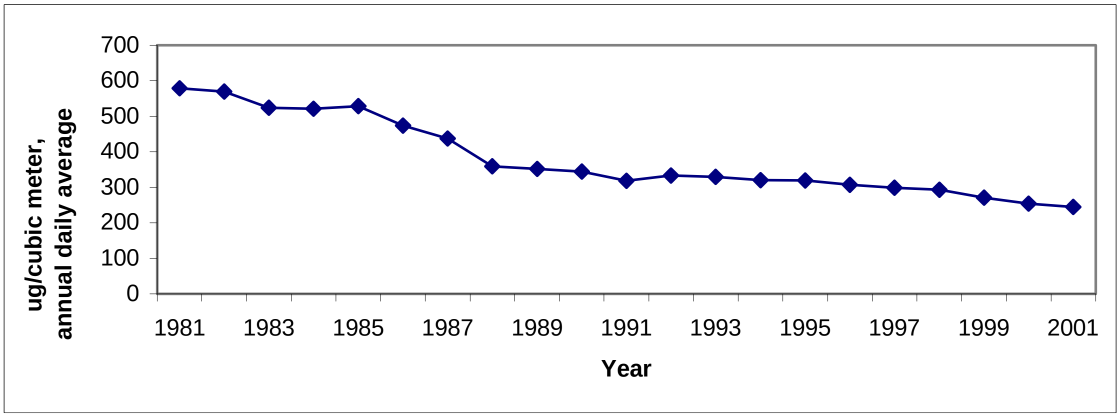


Figure 3. Ambient TSP (<40 Microns) Concentrations in Eleven Chinese Cities, 1981–2001



The statistical picture of pollution trends contrasts starkly with bleak qualitative reports by authors, such as Economy (2004). Indeed, the evidence in

Dasgupta et al. (2002), Gallagher (2003), and Diesendorf (2003) suggests that China's environmental regulations are ahead of where European countries were at similar levels of per capita income. What additional data might give a more complete picture of the trends in air pollution? Some areas of possible improvement are discussed later. The first issue pertains to the measurement of TSP and NO_x concentrations. A second issue concerns the decentralization of polluting industries and the lack of solid source–receptor data.

The measurement of TSP concentrations is complicated by its ambiguous components. Since TSP is the general name for particulate matter up to 40 microns in diameter, authorities measure the concentration of TSP per cubic meter of air. Nothing can be deduced about the small versus large particles within this cubic meter. The problem is that the most accurate measure of serious particulate pollution is fine particulate matter, or PM-10. While the United States monitors particulates as small as PM-2.5, PM-10 monitoring data in China are scarce (although daily monitoring of PM-10 has recently begun in some cities). Based on correlations between PM-10 and TSP in other data sets, a World Bank study (2001b**)** found that PM-10 is the most damaging air pollutant in China in terms of health complications.

The smaller particles are directly emitted from the combustion of fossil fuels and also result from postproduction photochemical reactions. The larger particles are the result of fugitive dust from wind and soil erosion and particles from industrial processes, such as metal and fiber production. So while total TSP emissions appear to be falling, it is unclear how the composition of the fine versus coarse particulates is changing. Concentrations of PM-10 may actually be increasing, even as TSP is decreasing, but this cannot be ascertained without more detailed information on the composition of TSP measurements.

There is a similar problem with the measurement of nitrous oxides. NO_x is measured as any combination of N and O, whether it be NO or NO_2 (as with TSP, authorities have begun measuring NO_2 separately, although not on a large-scale basis across the country). Uncertainty about the composition makes levels of NO_x difficult to compare with NO_2 gas concentrations reported in the United States and is referred to widely in the literature on air pollution epidemiology and health. Researchers have found that NO_2 level averages two-thirds of the NO_x level in China (U.S. Embassy Beijing, 1998).

In recent years, the government has begun to decentralize the polluting industries.[2] But as industry moves out of cities, the pollution data are still largely collected in these cities. It is possible then that total emissions may be increasing, but are more decentralized. Although it appears that urban China has stabilized or reduced ambient concentrations of the three major pollutants, air quality data are generally unavailable outside of major cities. Supplementary data are needed on the

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[2] SEPA's Ninth Five-Year Plan includes moving hundreds of polluters out of major industrial areas to curb pollution in those areas. In 2001, around 1 million square meters were cleared in Beijing as a result of relocations and another 6 million square meters are scheduled for clearing between 2001 and 2005. The city of Beijing wishes to move polluters out, making room for industrial marketing, research institutes, and more environment-friendly industries.

level of pollutants elsewhere, especially in the areas to which polluting industries are dispersing. Additionally, because source–receptor data are unavailable, it is hard to know how pollution created by specific industries affects various areas. Some will end up concentrated within the same city it was produced in; other polluters will have their emissions blown out of the region, with adverse impacts instead affecting downwind areas. It is not clear that current policies take these issues into account.

Although the statistics focus on large cities, the trend toward decentralization does have an important economic justification. Falling emissions in the cities means fewer people may be exposed to the pollution. It follows that decentralization of industry may significantly reduce health damages.

The Environmental Kuznets Curve

The EKC is a stylized fact according to which air pollution first increases and then falls as per capita income rises. The standard explanation is that environmental quality is a luxury good and that political economy forces induce environmental regulation accordingly. The rise and fall of the manufacturing sector relative to the whole economy and the comparative advantage that low-income countries have in the exportation of "dirty goods" are also cited (Grossman and Krueger, 1991; Panayotou, 1993; Lieb, 2002).

Figures 1–3 depict the population-weighted average ambient concentration levels of NO_x, SO_2, and TSP for eleven cities from 1981 to 2001. The majority of these eleven cities are major population centers. To investigate whether these pollutants followed the stylized EKC shape, we conducted a fixed-effects regression analysis for three pollutants in eighty cities from 1990 to 2001. Results for the three regressions are presented in Table 1 and are illustrated in Figures 4–6. While the order of emissions reaching their turning points in other countries is typically SO_2, TSP, and then NO_x (Brown, 2005), for China we find that the NO_x turns first at a per capita income level of around 28,000 yuan (approximately 3,461 U.S. dollars), followed by TSP around 44,000 yuan (approximately 5,440 U.S. dollars), and then finally SO_2, which is just reaching the flat portion of its curve around 58,000 yuan (or approximately 7,171 U.S. dollars). The order of the turning points appears to be reversed from that of Western countries, presumably due to the early fall in NO_x.

Table 1. *Regression Results*

Per Capita Emissions	NO_x Per Capita	SO_2 Per Capita	TSP Per Capita
GDP per capita	0.0000387 (5.77×10^{-6})	0.0001089 (0.0000174)	0.0002378 (0.0000607)
GDP per capita^2	-6.85×10^{-10} (8.11×10^{-11})	-9.09×10^{-10} (2.47×10^{-10})	-2.66×10^{-9} (8.51×10^{-10})
Year	−0.027 (0.0027)	− 0.113 (0.0081)	−0.251 (0.0281)

Constant	0.263	0.089	2.265
R-square	0.17	0.22	0.11
F-value	53.70	74.06	32.75

Note: Standard errors have been given in parentheses.

Figure 4. EKC for NO_x in Eighty Cities, 1990–2001

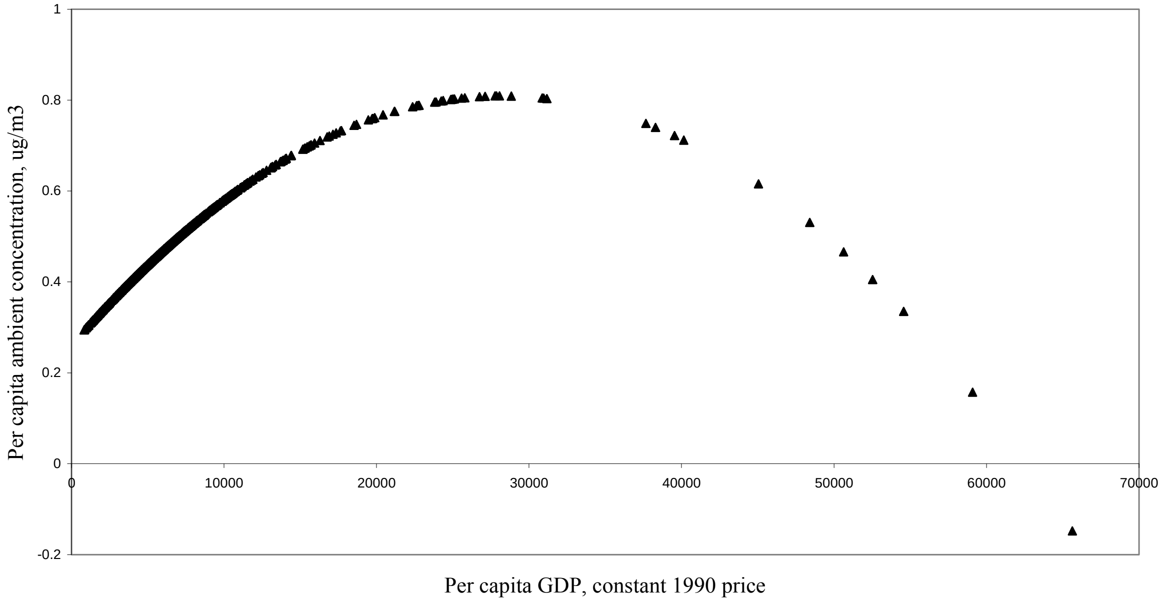


Figure 5. EKC for SO_2 in Eighty Cities, 1990–2001

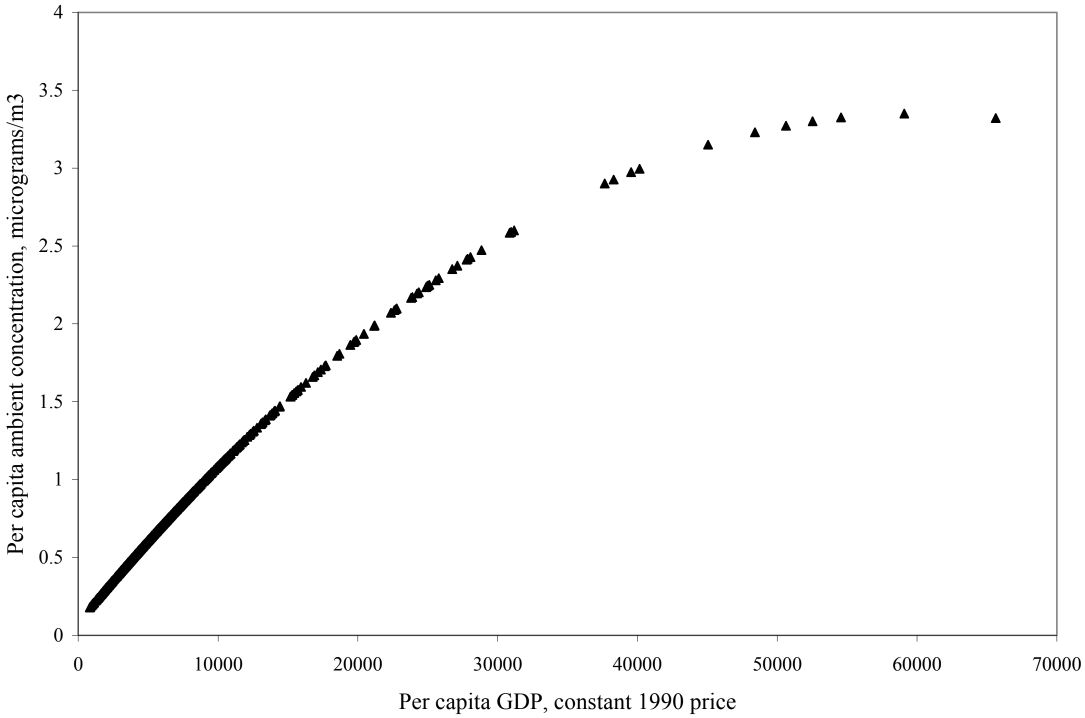
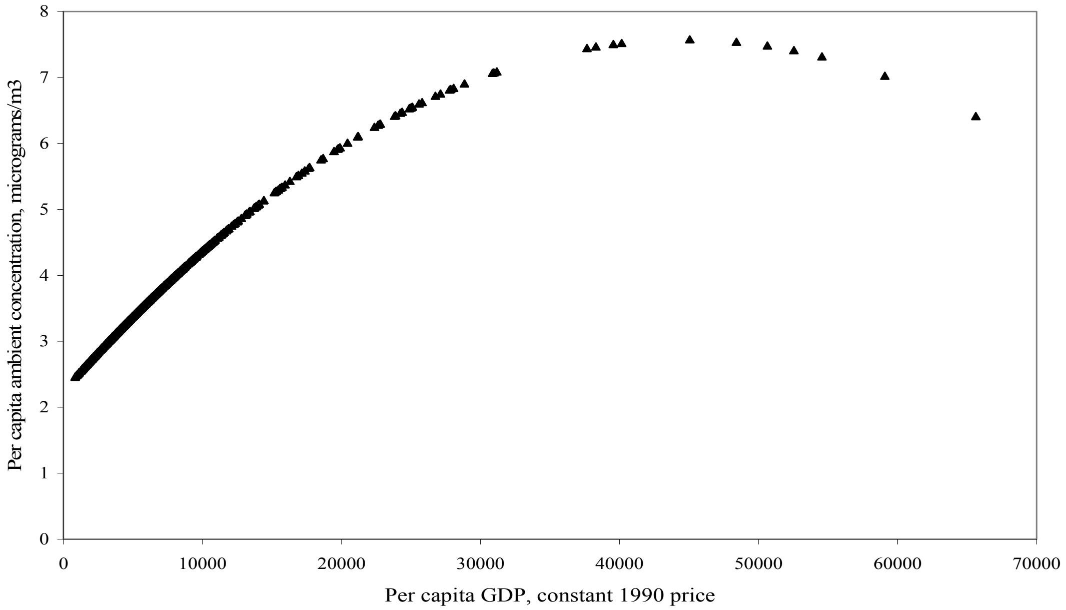


Figure 6. EKC for TSP in Eighty Cities, 1990–2001



The early turning point and the dramatic reduction in emissions of the NO_x EKC (Figure 4) may be an accurate portrayal of NO_x in industry, but may misrepresent what is happening to total NO_x, including mobile sources. Given the rapid increase in automobile ownership after our data period (1990–2001), it is quite possible that total NO_x is now increasing. In 2002, automobile purchases increased by 56 percent. In 2003, purchases grew by 75 percent and by another 15 percent in 2004, when the government tightened rules on credit for car purchases.[3] A 25 percent

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[3] "Dream Machines." *The Economist*. June 2, 2005, available at http://www.economist.com/business/displaystory.cfm?story_id=4032842.

increase in auto sales from 2005 to 2006, with sales reaching 7.22 million units, indicates a strengthening of auto consumer demand despite recent regulatory measures (*China Daily*, 2007). Indeed, a revised EKC for NO_x may eventually show two peaks. This helps to remind us that EKC is a stylized fact, not an economic law, and that the revealed pattern may not always conform to the simple one-turning-point case because of sectoral composition, trade patterns, and other complicating factors.[4]

The EKC for TSP takes the expected shape and the turning point is consistent with other studies. Falling per capita emissions despite rapid growth of heavy industry and manufacturing could reflect that either the country's reforestation efforts are indeed working or there is a problem with seasonal measurement (see section "Soil" for further discussion). There is also the issue of the exact makeup of TSP. While the smaller particles that are more detrimental to human health (less than 10 ppm) have begun showing up as separate measurements, it is not clear how the total composition had changed over time. Another issue that may be leading to the decrease in reported emissions is that manufacturing activities have, to some extent, moved away from city centers, even though the receptors that monitor pollution have remained relatively fixed. Finally, China appears to be just reaching the flat portion of its EKC for SO_2 emissions.

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[4] The NO_x discussion is suggestive of a "weak EKC hypothesis" according to which emissions increase in the early stages of development and decrease in the latter stages. In intermediate stages of development there may be one or more turning points.

Auffhammer, Carson, and Garin-Munoz (2004) found that most areas in China are likely approaching the flat portion of the EKC for CO_2; that is, further increases in per capita income will not tend to cause increases in per capita carbon emissions. Using more recent data, however, Auffhammer and Carson (2006) came to a very different conclusion. Utilizing a provincial-level panel data set with 588 observations (thirty provinces from 1985 to 2004), CO_2 emissions are forecast to increase dramatically over the next decade. The authors conclude that China's CO_2 emissions are highly unlikely to peak in the coming decade absent a dramatic change in energy policies and question the stationarity of EKCs in light of structural economic shifts, especially over space.[5] On the other hand, CO_2 may be the exception that proves the EKC rule.

Inasmuch as carbon emissions are a global public good, the effect of rising incomes on the demand for cleaner air would not be expected to appreciably increase regulations aimed at reducing carbon emissions. Another cause of the EKC pattern is that in the course of economic development, the relatively clean service sector grows faster than the manufacturing sector, and emissions eventually decline accordingly. In China's case, however, vigorous relative growth of manufacturing has persisted beyond the typical level of per capita income because of the larger role of exports in China's development. Finally, Auffhammer and Carson proxy CO_2 emissions by

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[5] The authors suggest that the magnitude of the projected increase is several times larger than the recommended carbon reductions induced by the Kyoto Protocol and that China's carbon emissions will surpass U.S. carbon emissions by 2010.

waste-gas emissions, which are presumably positively affected by the rapid growth in the stock and use of automobiles.

These observations suggest that China’s emission history is mostly consistent with the EKC hypothesis and indicates that total pollution per capita may have stabilized or begun to fall, despite rapidly increasing production. This conclusion is limited by the possibilities of measurement error in NO_x and TSP and by the mitigating effects of decentralization and increased automobile ownership. Nonetheless, it appears that China’s regulatory policies have achieved an overall turning point in air pollution, especially in terms of exposure,[6] at a per capita income less than the income level at which European countries reached peak levels of contamination.

Water Pollution

Much less progress has been made with respect to water quality improvements. Water pollution problems are especially severe in the North, particularly in the catchments of the Hai and Huang (Yellow) rivers and in the Huai in central China. The last decade has brought improvement to some of the larger rivers even as the total picture continues to deteriorate. It has been said that even if all point sources that empty into these northern rivers complied 100 percent with national discharge standards, the river systems would still be environmentally overloaded. Freshwater lakes and coastal water quality have not improved, and there is evidence that

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[6] Exposure is a measure of pollution that weighs emissions according to exposed population.

groundwater pollution may be increasing (World Bank, 2001b). The most problematic pollutant is organic material from industrial and domestic sources.

Table 2 shows water quality[7] of some major rivers. The rivers evaluated include the southeast, southwest, and northwest systems, including the Songhua, Liao, Hai, Huai, Huang, Changjiang (Yangtze), and Zhu (Pearl) rivers. These rivers drain over 45 percent of total land area and account for more than 54 percent of its freshwater resources. While the total length of the rivers evaluated continues to increase, the percentage "above standard" remains fairly constant, signaling falling water quality in more water bodies.

Table 2. *Water Quality Trends in China's Rivers, 1997–2003*

	Water Class	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**
Total length of rivers evaluated (km)		65,405	109,700	113,600	114,043	121,010	122,602	134,593
% in water class	I		5.4	5.5	4.9	5.0	5.6	5.7
	II	32.8	24.4	24.5	24.0	27.6	33.1	30.7
	III	26.3	33.0	32.4	29.8	28.8	26.0	26.2

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[7] China's water bodies are divided into five classes according to their utilization and protection status: Class I applies to the water from remote sources and national nature reserves. Class II consists of "protected areas for centralized sources of drinking water, the protected areas for rare fishes, and the spawning fields of fishes and shrimps." Class III applies to the "second class of protected areas for centralized sources of drinking water and protected areas for the common fishes and swimming areas." Class IV covers "the water areas for industrial use and entertainment which is not directly touched by human bodies." Class V applies to "water bodies for agricultural use and landscape requirement."

	SUBTOTAL ("above standard")	*56.4*	*62.8*	*62.4*	*58.7*	*61.4*	*64.7*	*62.6*
	IV		13.7	12.6	16.1	14.2	12.2	10.9
	V	27.7	6.6	7.8	8.1	7.8	5.6	5.8
	V+	15.9	16.9	17.2	17.1	16.6	17.5	20.7

If we were to separate these percentages for the North and South, the percentage of poor-class water bodies would be significantly higher in the North. The incidence of Class V and worse tends to be about three times higher in the North (World Bank, 2001b). Rapid industrialization of the North, with its accompanying population growth, means that more people are relying on increasingly worse water supplies. The number and probably the proportion of people using the poorer classes of water are likely to be rising. Table 3 documents similar trends in the country's lakes.

Table 3. *Water Quality Trends in China's Lakes, 1998–2005*

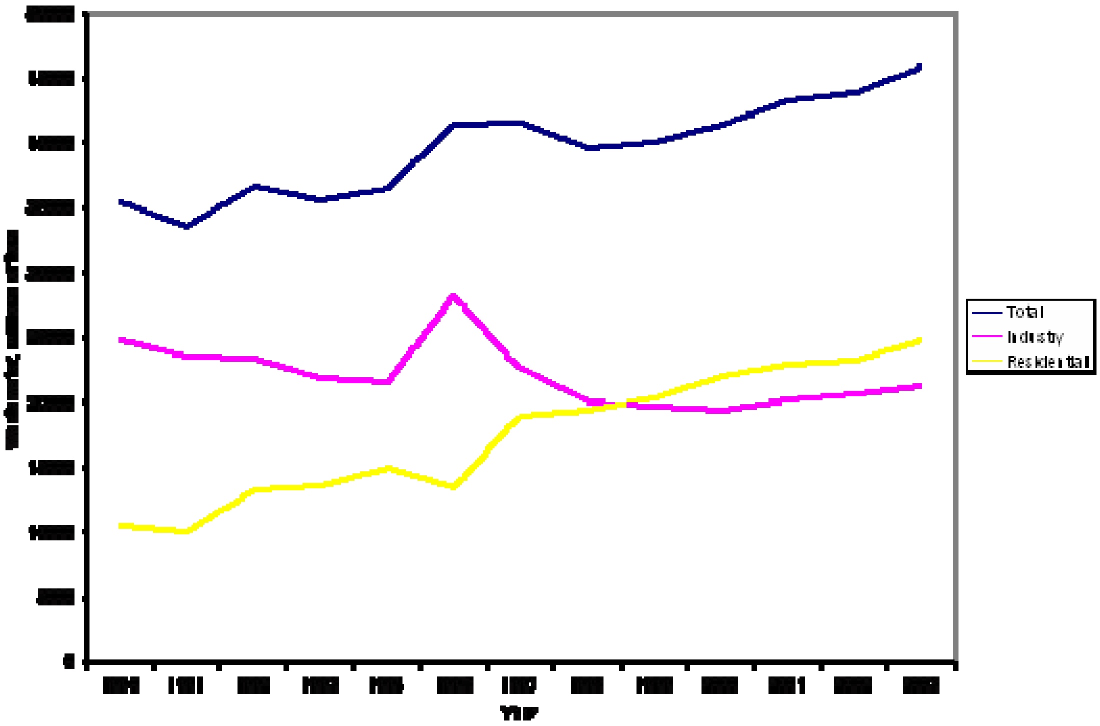
	Water Class	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**January 2005**
Total number of lakes evaluated		16	24	24	24	24	52	52

% in water class	III or above	37.5	41.7	37.5	41.7	25.0	40.4	40.4
	Partially polluted	25.0	20.8	16.7	8.3	25.0	9.6	9.6
	Severely polluted	37.5	37.5	45.8	50.0	50.0	50.0	50.0

Class V and worse water continues to be used by households and agriculture, posing dire health risks. SEPA samples do not include smaller rivers, which are said to be in extremely poor shape as a result of the discharge from township village enterprises (TVEs). Water quality in the Huai River is reportedly getting worse again, despite considerable effort by the government. In Guiyu, in Guangdong Province, levels of lead in the water were 2,400 times higher than WHO drinking guidelines (Economy, 2004).

Furthermore, total wastewater discharge is increasing, particularly in the residential sector. Although increased regulations have ameliorated industrial discharge, the total amount of wastewater is increasing. Confounding the problem is the increasing reality of water shortages. The combination of growing waste discharge (see Figure 7) and shrinking water flows exacerbates the already serious water pollution issues. This situation is illustrated in Figure 7.

Figure 7. Wastewater Trends, 1990–2003



In the absence of comprehensive time-series data on groundwater quality, information concerning groundwater quality remains anecdotal. Groundwater usage is poorly controlled. Excessive extraction has become common, particularly in the North. Anecdotal evidence suggests that groundwater quality is deteriorating, especially in near-surface aquifers and the vicinity of major cities (World Bank, 2001b).

NATURAL CAPITAL

Forests

Centuries of population growth have burdened China with a long history of deforestation. In addition, China spent the second half of the twentieth century overexploiting its timber resources and then mandating reforestation/afforestation (Yearbook, 2005).[8] The forestry management regime is split between the state and the local communities. State management covers only about 20 percent of the total resources, although this segment contains the higher-quality trees. The remaining reserves are collectively managed forests, which are owned by local communities and operated by village leaders.

Government's concern over the high levels of timber cutting was first documented in 1950 when the government issued "Instructions on the Work of National Forestry" to stop the random felling of trees (China Report). Afforestation became a government prerogative the next year, mandated in "Instructions on Strengthening the Leadership for the Work of Forestry" (China Report). Despite the government's efforts, forest cover continued to decrease to 12 percent of China's 96 million square kilometers of land area, as calculated in the Third Forest Census of 1983–1987 (Yearbook). This is approximately 115,250,000 hectares of forestland (Yearbook). Subsequent data show a slight recovery due to increases in both

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[8] Reforestation is the process of encouraging forest growth in lands that were previously forested, basically replenishing depleted forests. Afforestation is the process of converting previously unforested land into forests, or the process of forest creation.

afforestation and reforestation (see Tables 4 and 5). The proportion of afforestation for the purpose of timber harvest declined dramatically in the late twentieth century, while the lands designated for nature preserves increased substantially.

Data for the volume of timber harvested no longer appear among the industrial indicators in the Yearbook after 1987. This may reflect the government's decision to scale back the timber industry. The timber harvest peaked volumetrically in the late 1980s and has declined since then.

Table 4. *Trends in Forest Resources, 1981–2004*

Year	Forested Area (M Ha)	Forest Cover (%)	Forest Volume[a] (B m^3)
1981–1982	119.78	12.50	9.35
1983–1987	115.25	12.00	10.26
1988–1990	124.65	12.98	9.141
1991–1996	128.63	13.40	10.868
1997	133.70	13.92	11.785
1998–2002	158.94	16.55	12.49
2004	174.91	18.22	13.618

[a] Forest Standing Stock.

Source: Yearbook (various year).

Table 5. *China's Forests: Trends in Planting, Harvesting, and Protection, 1952–2004*

Year	Total Afforested Area (M Ha)	Afforested for Timber Area (%)	Timber Production (M m^3)	Nature Reserves (M Ha)
1952	1.085	0.50, 46.08	12.33	n.a.
1957	4.355	1.73, 39.84	27.87	n.a.
1965	3.426	1.72, 50.41	39.78	n.a.
1978	4.496	3.13, 69.62	51.62	n.a.
1984	8.254	5.06, 61.38	58.00	n.a.
1989	5.0233[b]	n.a.	89.64[a]	22[c]
1993	5.9034[b]	2.504,[b] 42.42	63.92[b]	66.18[d]
1999	4.9007[b]	1.418,[b] 28.93	52.36[b]	88.15
2000	5.105	1.21, 23.86	47.23[b]	98.21
2001	4.953	0.90, 18.28	45.52	129.89
2002	7.7709	0.89, 12.73	44.361	132.95
2003	9.1188	1.17, 12.98	47.58[b]	143.98
2004	5.598	0.87, 15.56	51.97[b]	148.23

[a] Value calculated based on Timber Industry Production Index found in China Report: Social and Economic Development.

[b] Data taken from China's *Forestry Statistics Yearbook* (various years).

[c] 1988 value.

[d] Data taken from China's *Environmental Statistical Yearbook*.

Source: Data taken from Yearbook (various years).

The reforms of the 1980s included policies to encourage afforestation and limit overharvesting. These policies aimed to change the management practices of state forestry enterprises and also to influence the actions of farmers and forest dwellers. There is great disagreement about the outcome of these reforms. Some observers cite an 8.5 percent increase in national forest cover between 1980 and 1988 as evidence of success (Yearbook), while others have asserted a negative impact. Rozelle et al. (1998) provide evidence that policy changes in the state sector did stimulate reforesting, but provided few incentives to curtail high rates of harvesting. Indeed, according to Economy (2004), forest resources are characterized by decreasing reserves and illegal logging. In the first years of reform, logging increased by 25 percent, consistent with the volumetric peak in timber harvests late in the 1980s. The country is now the world's second largest consumer of timber.

A U.S. Embassy report identifies deforestation as the root cause of the increased damages caused by the Yangtze River floods in 1998. It reports that forest cover in Sichuan Province decreased from 19 percent in 1950 to a low of 6.5 percent and that the average tree-cutting rate was more than double the natural tree growth rate. The Earth Policy Institute reports that by 1998, the Yangtze River basin had lost 85 percent of its total forest cover (Brown, 1998). Destruction of forests results in water storage losses as well as silting of the riverbeds and lakes. The Ecological Section of the SEPA (reported in the U.S. Embassy document) calculates that removing 70,000 hectares of forest eliminates 1 million cubic meters of natural water storage. In addition, the root systems of trees help anchor the soil, preventing silt from raising the height of the riverbed and, consequently, the heights of the floodwaters. Timber harvest rates dropped significantly following the flood crisis.

In response to this loss of forest cover, the government started the conservation set-aside (or offset) program “Grain for Green” in 1999. Easily one of the largest conservation set-aside programs in the world, its main objective was to increase forest cover on sloped cropland in the upper reaches of the Yangtze and Yellow River basins to prevent soil erosion. When available in their community, households set aside all or parts of certain types of land and plant seedlings to grow trees. In return, the government compensates the participants with grain, cash payments, and free seedlings. By the end of 2002, officials expanded the program to twenty-five (of thirty) provinces. To date, 7 million hectares of cultivated land has been converted to forest and pasture land.[9]

While this afforestation program certainly reduced domestic food production, the land that was removed from tillage was of such low quality (much lower quality than the average land that was opened up during the 1980s and 1990s to compensate for cultivated land lost to urbanization) that the program had only a marginal impact on overall food prices (Rozelle, Uchida, and Xu, 2005). Additionally, afforestation campaigns in general, which have had a long history in the country, are often undertaken with inappropriate technologies and poor oversight.

Therefore, despite increased biomass, the value of China's forests may have declined in recent years. Afforestation is taking place on lower-quality land as opposed to natural forest habitats and is further from market centers. As a result, neither the potential biological nor market benefits are being delivered with the optimal effectiveness, for example, regarding the appropriate composition of fast-growing versus high-value trees. Rozelle, Huang, and Benziger (2003) also report evidence that the increase in aggregate forest cover experienced between 1980 and 1993 came at the expense of forest diversity. With natural forests transformed into plantations, the ability to provide environmental services, such as species habitat, has

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[9] "Impact of WTO Accession on China's Agriculture, Rural Development, and Farmers," by Li Xiande, Institute of Agricultural Economics, Chinese Academy of Agricultural Sciences. May 16, 2006, presentation to World Bank Institute Beijing, available at siteresources.worldbank.org/INTRANETTRADE/Resources/WBI-Training/288464–1152217173757/Session20_LiXiande.pdf

declined. The change in forest structure may also affect the livelihoods of certain populations, as well as contribute to growing desertification and increased sandstorms in the North.[10] Unfortunately, the official statistics do not allow complete verification of these apparent trends. We have data on deforestation and reforestation, but no good indicators of actual stock levels. Furthermore, the total reforestation is not reported, only what is reforested in a given year. And because the age distribution of the timber stock is unknown, it is impossible to estimate the value of this resource. Better reporting would account for the changing *stock* of forest resources, including quality, location, and age distribution.

Water

Rapid economic growth has led to an increased demand for water, increased water pollution, and a change in sources of water pollution. Table 6 describes the change in total water resources in China in recent years, and Table 7 reports supply and consumption patterns.[11] Although the national supply of freshwater, 2,500 cubic meters per capita, is above the World Bank's definition of a water-scarce country, the geographic distribution of China's water resources is highly uneven. Availability is greatest in the South, where average rainfall is as much as nine times greater than that in the Northwest. The northern rivers have far less assimilative capacity than

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[10] In May 2000, then Premier Zhu Rongji warned that the rapidly advancing desert would necessitate moving the capital from Beijing (Economy, 2004).

[11] Surface water refers to the water volume from rivers, lakes, and glaciers, that is, the surface runoffs of natural rivers, lakes, and so on. Groundwater is the water from precipitation and surface water that seeps into the ground and is potentially available via pumping. The total water resource figure is found by summing the surface water and groundwater and then deducting the overlapping portion.

southern rivers, due to lower flows. Distribution of groundwater resources is also skewed – the South gaining four times more than the North. Most of the water is directed toward agriculture. (Eighty-five percent arable land in the North is irrigated, compared with 10 percent in the United States.)

Access to water resources is increasing due to investments in water resources engineering. As of 2000, 85,000 dams had been constructed with a total storage capacity of 518 billion cubic meters, of which 397 are large sized with a total storage capacity of 326.7 billion cubic meters and 2,634 are medium sized with a total storage capacity of 72.9 billion cubic meters. Their engineering projects also include 270,000 kilometers of embankments and ninety-eight flood storage or detention zones for the Yangtze, Yellow, and Huai rivers, with a total area of 34,500 square kilometers and a total storage capacity of 100 billion cubic meters (Ministry of Water Resources).

Table 6. *Total Water Resources in China*

Year	Precipitation	Ground Water	Surface Water	Overlap of Ground and Surface Water	Total Water Resources
1997	5,816.90	694.20	2,683.50	592.20	2,785.50
1998	6,763.10	940.00	3,272.60	810.90	3,401.70
1999	5,970.20	838.70	2,720.40	739.50	2,819.60
2000	6,009.20	850.20	2,656.20	736.30	2,770.10

2001	5,812.20	839.00	2,593.30	745.50	2,686.80
2002	6,261.00	869.70	2,724.30	768.50	2,825.50

Note: Values are in billion cubic meters.

Source: Ministry of Water Resources, China.

Table 7. *Water Supply and Consumption in China*

Year	Water Supply	Water Consumption	Water Depletion	Depletion as % of Consumption
1997	562.30	556.60	317.80	57.10
1998	547.00	543.50	306.20	56.34
1999	561.30	559.10	302.80	54.16
2000	553.10	549.80	301.20	54.78
2001	556.70	556.70	305.20	54.82
2002	549.70	549.70	298.50	54.30

Note: Values are in billion cubic meters.

Source: Ministry of Water Resources, China.

Rapid economic growth and a growing population have increased demand. Historically, government has met rising demand via dams and other public works that capture a greater percentage of available surface water and increase total water storage. These are increasingly expensive per unit of water made available and their remaining potential quite limited.

There is evidence of falling water tables, especially in the northern regions. A study conducted in 2001 by the Geological Environmental Monitoring Institute in Beijing reported that in Hebei Province, the average level of the aquifer dropped 2.9

meters in 2000.[12] In some cities around the province, it fell by nearly 6 meters. The water deficit (a summation over time of the extent water supplies is below average) in the North may now exceed over 40 billion tons per year.

The most recent water projections suggest that irrigation use will decline from 73 percent of total consumption to 50 percent in 2050 (World Bank, 2001b). Consumption for industrial and urban purposes, however, is expected to increase substantially. Since both of these forms of consumption lead to emissions of polluted water, it will be increasingly difficult to maintain water quality. The UNDP, UNEP, World Bank, and the World Resources Institute define water scarcity as 1,000 cubic meters per person or less. The water consumed per person (from both surface and groundwater) includes not only what is normally classified as domestic/residential water consumption per capita, but also the individual's share of national water consumed for productive activities – agriculture and industry – and the individual's share of water required for ecosystem needs. Using this definition of water scarcity, the country as a whole will be classified as water scarce by 2010 at the current rate of population growth (Shalizi, 2004).

There is no clear solution to the enormous disparity in water supply between the north and the south of China, nor to the rising overall shortage in per capita supply. Although the country is implementing numerous water storage projects and building channels intended to transport large volumes of water from south to north,

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[12] http://www.thestudentzone.com/articles/chinawater.html.

the trends of these supply stresses show that they are likely to overwhelm such efforts. In particular, the South to North Transfer Project commenced construction in 2002 and is expected to deliver its first benefits to Beijing residents in 2008. The project consists of three canals covering 1,300 kilometers, transferring water from the lower, middle, and upper reaches of the Yangtze River by channeling it to the Yellow, Huai, and Hai rivers. The Ministry of Water Resources estimates that 94 percent of the volume of the Yangtze River annually flows into the East China Sea. The project is expected to cost 59 billion U.S. dollars and take fifty years to complete (MWR, 2007). A U.S. Embassy report questions the engineering feasibility of certain aspects of the project, such as crossing the Yellow River, whose bed is rising annually due to siltation. Additional criticisms in the report address the lack of concern for environmental and supply effects to donor regions, especially in drought years, and for the water use rights of downstream localities (U.S. Embassy, 2000).

The severity of China's water problems varies widely across regions, with the greatest difficulties arising in the northwest and north China regions. Gross underpricing of water resources compounds the difficulties arising from rising production, population growth, and urbanization. Inevitably, the potential for successful water management must rest primarily with demand-side conservation.

Soil

Since the 1990s, desertification[13] has become a major land resource concern. Desertification affects some 262 million hectares, giving China the world's highest ratio of actual-to-potential desertification (World Bank, 2001b). The North (including the capital of Beijing) has been covered in dust for days at a time, dust that travels as far as Japan, Korea, and the United States. It has been estimated that 5 billion tons of topsoil is lost every year.[14]

A series of government-sponsored policies to increase grain production, partly in response to Lester Brown's *Who Will Feed China* (1994), exacerbated problems in land-use practices. A 1994 policy required that all cropland used for construction (industrialization trend) be offset by land reclaimed elsewhere. Coastal provinces paid other provinces to plow land to offset losses, and these provinces reclaimed vast tracts of grasslands and continued to plow more land. Overall, the campaign failed to achieve its objectives and created unintended consequences, including the substitution of poor-quality land for good-quality land.

Peter Lindert (2000) examined one aspect of Brown's challenge: can China feed itself? Lindert's analysis suggests that Brown's findings are somewhat exaggerated. Lindert shows econometrically that productivity does not necessarily decline with soil loss. There are a number of additional factors that would prevent loss of productivity despite loss of soil, for example, sufficient soil depth.

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[13] Desertification has been defined by the United Nations as "land degradation in arid, semi-arid and dry sub-humid areas, resulting from various factors, including climatic variations and human activities."

[14] China's Agenda 21, www.acca21.org.cn/english.

This is not to suggest that soil resources are being optimally managed. While on-site damages from lost soil may be low, off-site damages may be considerable, including siltation in irrigation systems, water transport systems, increased water pollution, nearshore effects, and health complications from increased windblown dust. These concerns appear to be more serious than productivity loss. Relatedly, asking whether China can feed itself may be the wrong question. While the country has increased imports, this is a sign of comparative advantage, not necessarily of an inability to be self-sufficient in food.

Energy

China is the world's largest producer and consumer of coal, which dominates domestic energy consumption and constitutes the chief source of air pollution. Rapid economic growth has led to a 5 percent annual increase in energy consumption. It is estimated that to meet projected electricity demands in 2020, China would need an additional 1.2 billion tons of coal per year (*People's Daily*). In its search for alternative sources of power, China has constructed mammoth hydroelectric generating dams, forayed into solar and wind technology, and, in the last two decades, invested significantly in nuclear power production. However, substantial reliance on coal, the source of most sulfur dioxide and soot emissions, continues. In 2000, the per capita stock of domestic reserves was 2.6 tons for petroleum, 1,074 cubic meters for natural gas, and 90 tons for coal. Forty percent of coal consumption is for electricity generation. Much of it is unwashed, perhaps in part because of the water shortages in Northern China.

Table 8 summarizes trends in China's consumption of coal. The data show rising coal use as well as important changes in the structure of consumption. Residential consumption declined by 50 percent between 1990 and 2003, reflecting substitution of natural gas and other relatively clean fuels for coal as well as new prohibitions against domestic coal burning in many cities. Final consumption of coal in industry rose and then fell, apparently reflecting widespread substitution of electricity (mainly coal-fired) for direct use of coal to power industrial processes.[15]

Table 8. Coal Use, 1990–2003

		Final Consumption		Intermediate Consumption		
Year	Residential	Industry	Total	Power Generation	Heating	Coking
1990	16,699.7	35,773.8	60,205.9	27,204.3	2,995.5	10,697.6

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[15] Colleagues suggest several explanations for the decline in industrial coal consumption (Wu Kang of East West Center and Jeff Brown of FACS, personal communication). First, more advanced equipment associated with growing industrialization has called for increased use of electric power. The direct use of coal in the industrial sector has, to a great extent, been replaced by coal-fired power, which is more energy efficient. Second, diesel is often favored over coal for its cleanliness and efficiency. Finally, high hauling charges discourage the transportation of coal and encourage the substitution of electricity and diesel. Moreover, imported equipment may run on diesel only, or on electric power. As a result, between 1995 and 2002, China's use of electric power in the industrial sector increased notably, the use of diesel was higher, while the use of coal declined. Other possibilities for this trend include the relatively longer time it takes to install coal-using capital equipment, increased oil demand due to the rapid increase in China's stock of motor vehicles, and the possible difficulty of rapid increases in coal production or even coal imports.

1995	13,530.1	46,050.3	66,156.1	44,440.2	5,887.3	18,396.4
2000	7,907.2	34,122.0	46,821.4	55,811.2	8,794.1	16,496.4
2003	8,174.7	35,981.2	49,044.8	81,976.5	10,895.5	23,639.9
2004	8,173.2	46,083.0	59,543.7	91,961.6	11,546.6	25,349.6
2005	8,739.0	48,040.7	62,154.1	103,098.5	13,542.0	31,667.1

Note: Values are in 10,000 tons.

Source: Yearbook (2006, Table 7.5).

At the same time, rising coal production has supported large increases in intermediate usage of coal for producing electricity and for heating and (commercial) cooking, all of which have recorded substantial growth. Coal consumption for power generation alone rose from 272 million tons in 1990 to over 1 billion tons in 2005. In addition, rising coal production has allowed China to become the world's second largest coal exporter after Australia, having jumped from 32 million tons in 1998 to more than 90 million tons of exports in 2001.[16] This figure continued to grow, reaching 94 million tons by 2003, before dropping to 87 and 72 million tons in 2004 and 2005 (Yearbook). Rapid export growth reflects government assistance to state-owned coal mines, export incentives, relatively low cost, proximity to Asian markets, expanded production capacity, and the desire of some Asian coal buyers to diversify their sources of supply.

Available figures also show important changes in the broader structure of energy consumption. Steep increases in the use of oil have led to an increase in the ratio of oil-to-coal use, although very recently, that trend has abated (Figure 8). Beginning in 1993, China's trade balance in petroleum turned negative; since then, net imports have risen steeply, reaching 138.84 million tons in 2006. This is a 17 percent increase from imports in 2005; net imports of refined oil were up 38 percent the same year (*China Daily*, 2007). Official forecasts anticipate further growth of

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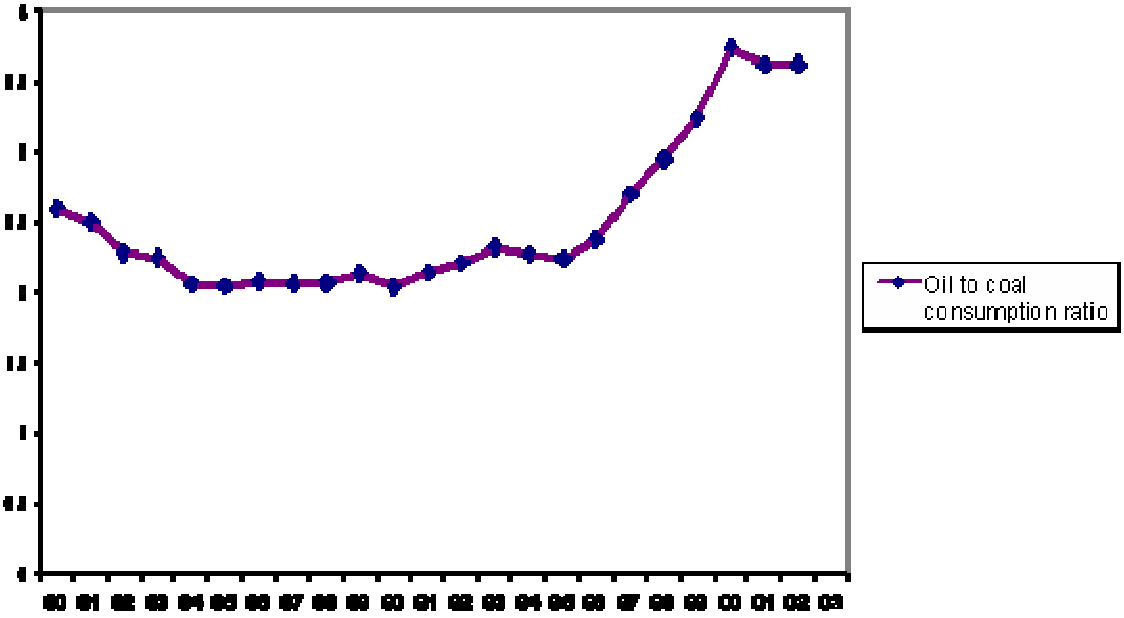
[16] Source: Geoff Hiscock, CNN Asia Business Editor. Monday, March 10, 2003, at CNN.com.

petroleum imports, which are expected to reach 60 percent of total consumption by 2020 (www.cei.gov.cn).

Figure 8. Oil-to-Coal Consumption Ratio, 1980–2003 (*Source*: http://www.eia.doe.gov/.)



China has also increased production of natural gas, which has largely replaced gasoline as the fuel for buses and taxis. In 2005, natural gas accounted for 3.3 percent of China’s energy output and 2.9 percent of consumption, both record levels (Yearbook, 2006, p. 261). Plans to construct facilities for large-scale imports of liquid natural gas underscore Beijing’s commitment to increase the role of natural gas in China’s energy economy.

Another effort in this direction is the use of photovoltaics, especially in remote southern areas. The success of this endeavor would cut down on transmission costs and provide a clean alternative energy source. To tap into the wind resources across the country, the country has invested 3.7 million U.S. dollars a year since 2003.[17]

China has embraced nuclear power as a partial solution to the overwhelming levels of pollution caused by their number one source of electricity: coal burning. The first nuclear plants in China began producing electricity in 1994, according to the World Nuclear Association (WNA). Three reactors were put into operation that year, one of which is the first to be designed and constructed entirely by Chinese corporations (China National Nuclear Corporation). In 2005, 2.1 percent of China's electricity was provided by nuclear power plants, a total of 52.3 billion kWh (WNA).

Overall, China appears to be taking clean and renewable energy efforts seriously. Taxation is the implementation tool of choice in most cases. The Standing Committee of the National People's Congress and the Ministry of Finance have recommended tax rebates for renewable energy usage, lower taxes on fuel-efficient cars, and relief from value-added taxes on energy-saving business investments, along with additional taxes imposed on nonrenewable energy usage. Other measures include requiring annual reports on energy use and efforts from energy-intensive industries, a focus on "green buildings" in new construction, sustainable

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[17] www.chinaview.cn, August 11, 2005.

transportation, and clean energy production (NDRC, 2004; Winning, 2006). China’s 2006 the Renewable Energy Law stipulates that renewable energy should account for 10 percent of energy consumption by 2020 (Renewable Energy Access, 2006). Also, the central government has called for a general investment slowdown (Oster, 2006), but this is not particular to more energy intensive industries and seems to be a general check on excessive growth.

As with water, underpricing undercuts efforts to reduce resource utilization. The low user cost of coal burning is especially problematic: at its 2005 annual meeting, China’s Senior Policy Advisory Council reported actual external costs of SO_2 emissions from coal combustion for thermal power generation of 0.0938 RMB/kWh, a figure ten times the emissions charges for coal combustion, currently sit at just 0.0096 RMB/kWh. Such inefficiency clearly provides inadequate incentive for Chinese electricity producers to promote reductions in SO_2 emissions (China Senior Policy Advisory Council Report, 2005).

Other Resources

Fisheries

China is the largest fish producer in the world and has the largest number of fishing boats. Since 1990, fish production has ranked first in the world, reaching around 40 million tons in 1999 and accounting for 30 percent of the world total. Years of overfishing have combined with growing water pollution to erode China's traditional fishery resources.

The expansion of aquaculture has had a profound impact on the structure of the fishery sector. Since 1978, the area of ponds, lakes, reservoirs, and seas used for aquaculture has steadily increased. In 1999, this area reached 7.75 million hectares, a threefold increase from 1978. Total aquaculture production increased from 1.60 million tons in 1978 (27 percent of total fisheries production) to 25.78 million tons (60 percent) in 2000 (Li, 2003). There has also been a notable movement of labor to aquaculture from agriculture/capture fisheries. By 1990, over 2 million people switched to aquaculture from agriculture and other industries. Total fishery (cultivation plus capture) labor in 2000 reached 18.6 million, of which full-time employment in the aquaculture sector reached 3.7 million, a sevenfold increase over 1978 level (Li, 2003). Other important contributions from aquaculture include improvements in fisheries techniques and yields, diversification of farmed species, and diversification in modes of farming.

Minerals

As of early 2003, total mineral reserves included 158 detected minerals, with 10 energy minerals, 54 metal minerals, 91 nonmetal minerals, and 3 liquid–gas minerals.[18] China possesses abundant deposits of metallic minerals, such as iron ore. As of 1996, estimated reserves of iron ore amounted to 46.3 billion tons, which placed among world leaders in this category, following Russia, Australia, Canada, and Brazil (Liu, 2007). Iron ore is found in most regions of China. The northeast and north China areas have the richest reserves, followed by the southwest. Among China's provinces, Liaoning ranks first in proved reserves, followed by Hebei, Sichuan, Shanxi, Anhui, Yunnan, and Inner Mongolia (Ministry of Land and Resources, People's Republic of China). Ore quality is generally low, however, with the average grade of China's iron ore at only 37.5 percent (Liu Haoting, from China's *Steel Industry Yearbook*).

While reserves of highly demanded minerals have been depleted, reserves of rare minerals such as tungsten, stibium, and rare earth elements are plentiful. Reserves of manganese, gold, and silver have been increasing steadily since the 1950s. In particular, from 1991 to 1995, total known gold reserves increased by over 300 percent. By the end of 1994, the reserve of rare earth elements[19] was 107.35 billion tons, the most in the world.

Despite the large scale of mineral resources, China's per capita reserves are low and falling. By 2020, dependence on imported crude oil is expected to rise to 60

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[18] Source: http://www.mlr.gov.cn/GuotuPortal/appmanager/guotu/index?_nfpb=true&_pageLabel=desktop_index_page_zygk.

[19] There are seventeen rare earth elements: scandium, yttrium, lanthanum, cerium, praseodymium, neodymium, promethium, samarium, europium, gadolinium, terbium, dysprosium, holmium, erbium, thulium, ytterbium, and lutetium.

percent and natural gas to 40 percent. According to projections of future supply and demand, by 2020, domestic resources will fully supply only nine of forty-five varieties. In particular, crude oil, iron ore, copper, and bauxite, items essential to national economic security, are all in long-term deficit.

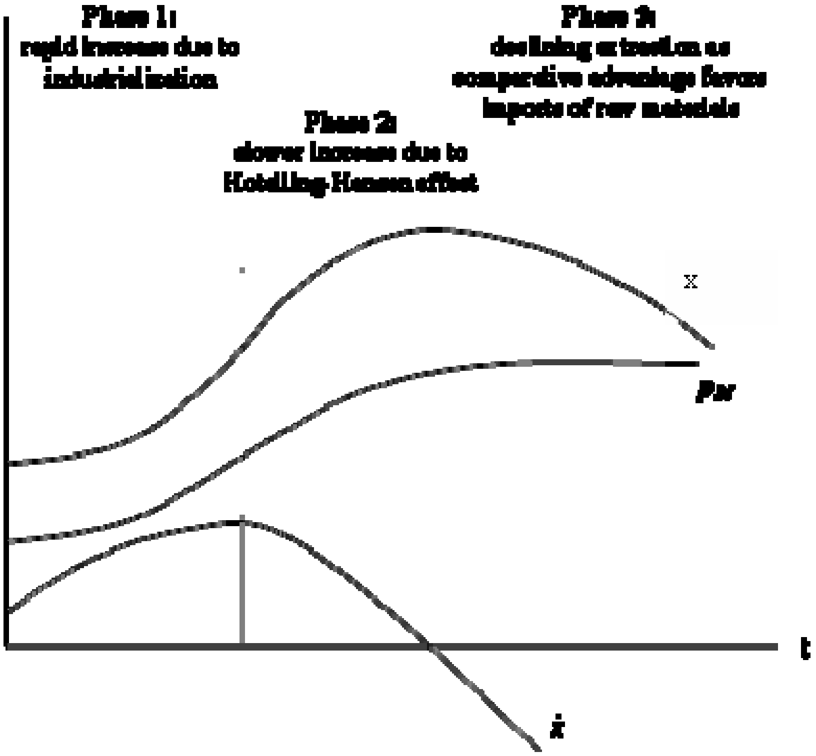
As the ratio of income and manufacturing output to domestic mineral resources continues to decline, future growth will require large imports of an expanding array of mineral products. The scale of future imports and the range of minerals needed have propelled Chinese efforts to establish a wide network of trade partners to supply these mineral demands. Declining mineral reserves implies that the country will become increasingly dependent on trade for nonrenewable resources. This dependence may lead China’s foreign policy to emphasize cooperative approaches to resolving contentious international issues (Brandt, Rawski, and Zhu, 2007).

NATURAL RESOURCES KUZNETS CURVE

Natural Resources Kuznets Curve Theory

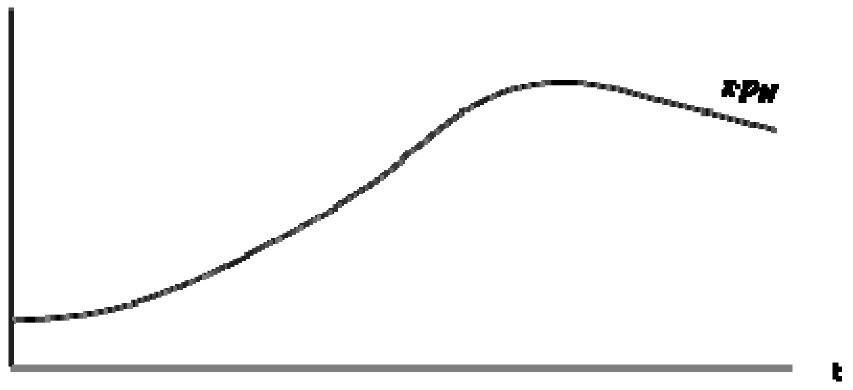
The EKC theory has been well developed in the literature. In this section, we propose a “natural resource Kuznets curve” (NRKC), whereby both resource extraction and the value of this extraction initially increase, reach a peak, and then decrease over time with increased wealth. Figure 9 illustrates the idea for a nonrenewable resource, where *t* is time, p_N represents the shadow price of the resource, *x* represents extraction of the resource, and the dotted variables represent the associated time derivatives. During early stages of development (phase 1), resource extraction increases as the economy industrializes. Extraction increases at an increasing rate, until rising extraction costs squeeze resource rents (Hotelling-Hansen effect, Hotelling 1931, Hansen 1980) causing the rate of extraction to decline, even in the face of rising demand. For a rapidly growing economy such as China, comparative advantage shifts to manufactured goods and away from the production of primary goods, including energy. Eventually increased demand for energy is sufficiently offset by increased energy imports that the Hotelling-Hansen effect dominates, thus causing extraction to fall, as shown in phase 3.

Figure 9. Phases of a Natural Resources Kuznets Curve



Based on the path of resource extraction and resource prices shown in Figure 9, we lay out the corresponding trend in the total value of resource extraction in Figure 10. Initially, the value of resource extraction increases as both price and the extraction rate rise. As the decrease in extraction rate comes to dominate the decelerating increase in resource price, the value of extraction begins to decline. This represents the Kuznets relation for the value of resource extraction.

Figure 10. Value of Resource Extraction over Time



A similar story can be told for renewable resources. In the initial phase, resources such as forests and fisheries are depleted; later on, in a second phase, the rate of depletion slows. In contrast to nonrenewable resources, renewable resources accumulate (or decline) according to the difference between the stock's natural growth rate and the amount harvested. As a result, the Kuznets peak will arrive sooner than with nonrenewables. In phase 3, total extraction will begin to fall as depreciation approaches zero. As capital accumulation increases the marginal product of renewable resources throughout the economy, and as comparative advantage induces increasing imports of renewable resource products, the domestic stock of renewable resources eventually increases; that is, harvest is less than natural growth plus replanting/restocking. In this phase, the value of net renewable resource depletion becomes negative.

NRKC Empirics

Using data from the World Bank’s Adjusted Net Savings Data Center (World Bank, 2001a), we calculate the value of a corresponding natural resource Kuznets curve for forests, minerals, and energy. Data for selected years are presented in Table 9. For net forest depletion, rent on depletion was calculated as the rent on that amount of extraction that exceeded the natural increment in wood volume. For mineral and energy depletion, rent was measured as the market value of extracted material minus the average extraction cost. Note that this estimate is a preliminary indicator. Ongoing data collection may make it possible to expand the estimate in the future to include other resources, such as soil, water, and marine resources.

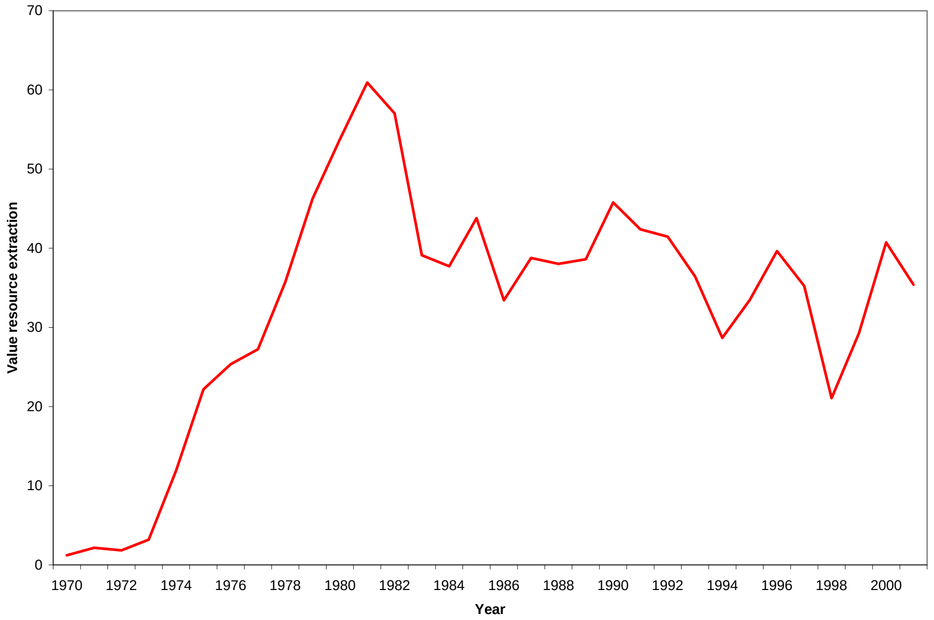
Table 9. *The Value of Resource Depletion, Selected Years 1975–2000*

Year	NNP	Net Forest Depletion	Mineral Depletion	Energy Depletion
1975	159.07	0.10	1.26	19.62
1980	213.85	0.35	1.83	38.66
1985	289.07	0.85	2.54	40.88
1990	412.76	1.39	3.28	33.58
1995	677.74	1.47	3.24	31.11
2000	1,061.41	0.73	2.65	31.76

Note: Values are in billions, 2004 U.S. dollars; ten-year moving averages are reported, with the exception of 2000, which is a three-year average.

We illustrate the NRKC by summing up the values of China’s forests, minerals, and energy depletion in Figure 11. T' represents the peak of the NRKC for this series. The peak’s relationship to the growth rate of a green accounting income measure is examined in the next section.

Figure 11. Natural Resource Kuznets Curve: Value of Resource Depletion, 1970–2001 (*Source*: World Bank, 2001a,2001c, 2004.)



GREEN NET NATIONAL PRODUCT

GNNP: Theory

A central pillar of the sustainability movement is the call to include environmental accounting in standard measures of economic performance. This increased transparency would, in principle, mitigate the temptation of economic managers and policymakers to increase growth in material consumption at the expense of the environment. Moreover, as Repetto (1989) and others have argued, deducting depreciation of produced capital from NNP but not deducting depreciation of natural capital is inconsistent and debases NNP as a possible indicator of welfare. In addition to deducting the depreciation in natural capital, GNNP treats pollution in a more appropriate fashion. While defensive expenditures to limit pollution are counted as production in current NNP accounting, the correct practice is to deduct both defensive expenditures and pollution, valued at its marginal damage cost. Accordingly, defensive expenditures must be deducted twice from the standard accounts.

The theoretical framework for GNNP requires consideration of three separate categories: nonrenewable resources, renewable resources, and pollution (stock and flow). For distinction, we refer to GNNP as the complete green income measure (subtracting both the depreciation of natural capital and the pollution damages) and GNNP' as excluding adjustments for pollution. For nonrenewable resources in a closed economy, GNNP' grows faster than NNP if and only if $\dot{y}p_N x - y(\dot{p}_N x + p_N \dot{x})$ > 0, where *y* represents NNP, p_N represents the first-best shadow price of the resource, *x* represents extraction of the resource, and the dotted variables represent the associated time derivatives.[20] In the early stages of economic growth, both a country's resource extraction rate and the price of the resources are increasing, resulting in GNNP growing more slowly than NNP. (That is, the second term dominates the first.) In later stages, the change in resource extraction decreases due to increased resource scarcity and – in the case of a rapidly growing economy – to the shifting comparative advantage in manufactures relative to resources. Moreover, the Hotelling-Hansen effect causes the rate of the price increase to decline. The two

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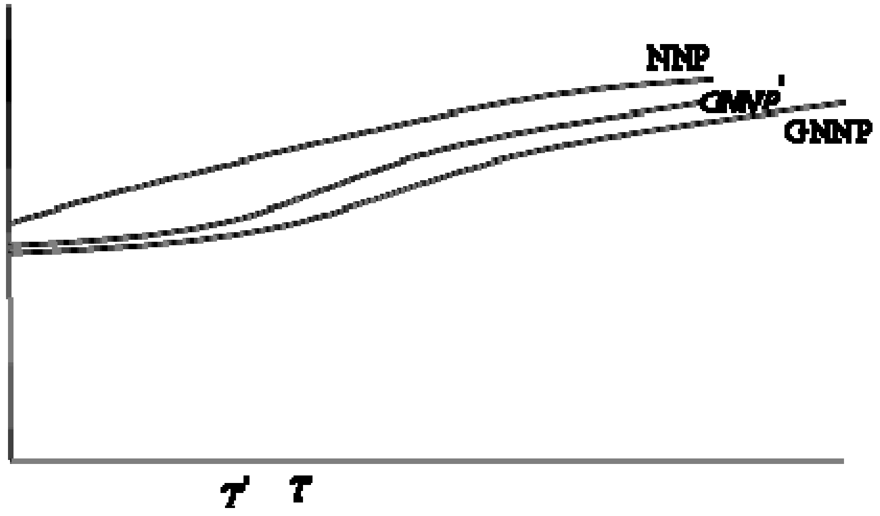
[20] This condition is obtained by taking the time derivative of GNNP.

forces combine to make the first term dominate the second (and the second term to eventually become negative). Thus $\text{GNNP}^{'}$ (i.e., adjusting for resource depletion but not pollution) will grow faster than NNP, as illustrated in Figure 12.

Figure 12. Growth of NNP versus GNNP′ and GNNP



$T^{'}$ in Figure 12 corresponds to the peak of the NRKC described in section "NRKC Empirics" earlier and represents the point at which $\text{GNNP}^{'}$ will begin growing faster than NNP. As suggested by Figure 11, China has already passed this peak. With optimal management, stock pollution, for example, coral reef sedimentation, will demonstrate an EKC similar to NRKC. Adding pollution to $\text{GNNP}^{'}$ results in a complete green income measure, GNNP. Growth of GNNP will become faster than NNP at point *T*. Because the EKC for China peaks later than the

NRKC and because of an additional price effect (pollution is a normal good), T is shown as greater than $T^{'}$.

GNNP: Empirics

In what follows, we provide a partial estimate for GNNP by subtracting three components from NNP: net forest depletion, mineral depletion, and energy depletion.[21] Data are in 2004 U.S. dollars. Table 10 provides the value of each component.

Table 10. *Partial Estimate of Green Net National Product, Selected Years 1975–2000*

Year	NNP	Net Forest Depletion	Mineral Depletion	Energy Depletion	GNNP
1975	159.07	0.10	1.26	19.62	138.08
1980	213.85	0.35	1.83	38.66	173.02
1985	289.07	0.85	2.54	40.88	244.80
1990	412.76	1.39	3.28	33.58	374.50
1995	677.74	1.47	3.24	31.11	641.91
2000	1,061.41	0.73	2.65	31.76	1,026.28

Note: Ten-year moving averages are reported, with the exception of 2000, which is a three-year average.

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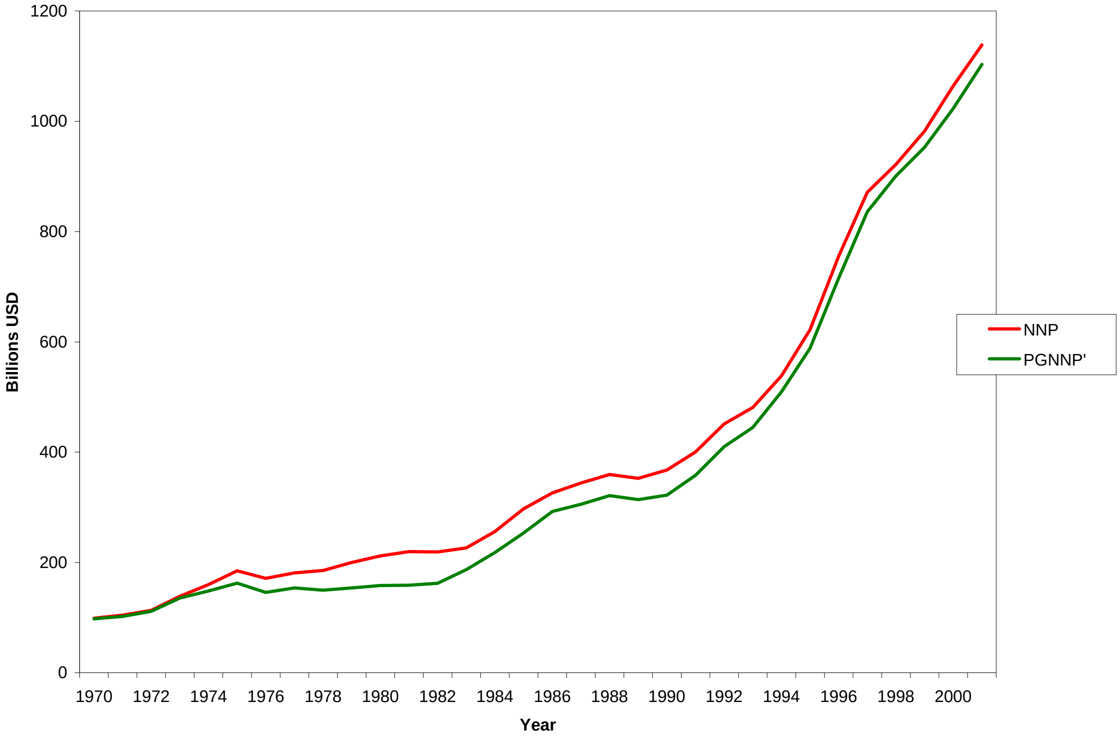
[21] Forest, energy, and mineral depletion data were obtained from the World Bank's "Adjusted Net Savings: Results" spreadsheet, downloaded from www.worldbank.org/environmentaleconomics, December 1, 2004. GNI data from World Bank's World Development Indicators, 2004.

Figure 13 illustrates the growth of NNP versus our partially corrected measure, denoted PGNNP'. Unlike the theoretical construct, which is based on efficient extraction profiles, the empirical growth rates are more uneven and illustrate the possibility that PGNNP' can grow slow, faster, and then slower again than NNP in contrast to the theoretical pattern that has only one such switch point.

Nonetheless, the empirical pattern approximates the theoretical one; that is, until the early 1980s, NNP was almost always growing faster than PGNNP', but starting in 1982, the pattern was reversed with a few exceptions. Note also that the difference in NNP and PGNNP' is rather small and after the mid-1980s, growth in PGNNP' is closely approximated by NNP. Overall, the partial evidence given earlier suggests that China has already reached the point in the theoretical depiction where GNNP starts to grow faster than NNP. As data become available on the value of air and water pollution, however, a more comprehensive GNNP may reveal a later turning point at which GNNP begins to grow faster. Inasmuch as the growth rates of the two measures are quite close, however, even a revised estimate would not show GNNP growing appreciably slower than NNP. To the extent that actual pollution and natural resource extraction vary from their optimal quantities, the potential remains for GNNP to grow even faster, as resource and environmental inefficiencies are removed over time.

Figure 13. NNP versus $\text{PGNNP}^{'}$, 1970–2001



(*Source*: World Bank, 2001a, 2001c, 2004.)

GNNP accounting is still evolving, as statisticians struggle to design measurement protocols that conform to new theoretical requirements. As a result, we find numerous of partial estimates that explore the gap between conventional and green national accounts and obtain differing results (Smil, 1996; Mao et al., 1997; ; Du, Wang, and Long, 1999; Hou, Qi, and Yu, 1999; Lei, 1999). Most recently, in 2004, SEPA and the National Bureau of Statistics enlisted provincial and local authorities in an effort to quantify green GDP. The team released the first national green-GDP report in September 2006, estimating total losses for 2005 at 64.5 billion

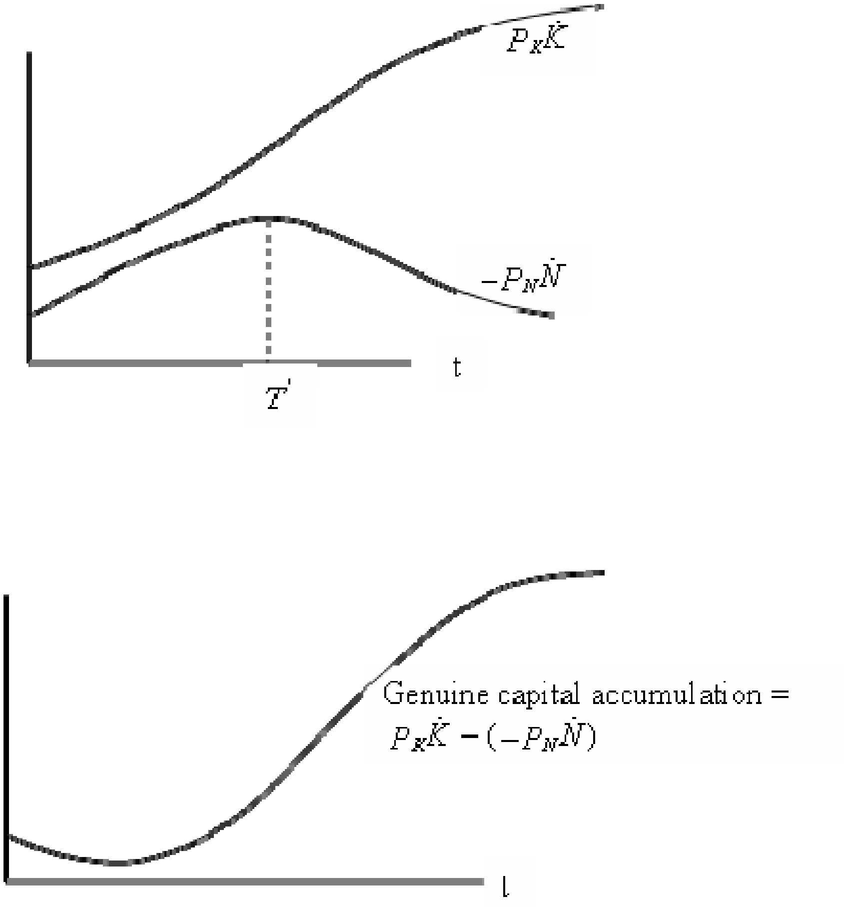
U.S. dollars (Ansfield and Liu, 2007). How much of this difference arises from the comprehensive nature of the 2006 report versus the partial estimates reported earlier (e.g., the 2006 report includes both soil depletion and water pollution) and how much is due to methodological differences is not yet clear. It is possible that the more comprehensive measure would show that sustainable development in China has not yet reached the turning point where GNNP is growing faster than NNP.

GENUINE CAPITAL ACCUMULATION

Genuine Capital Accumulation: Theory

Growth theory provides a mechanism to expand national accounting and an indicator of when economies are on an unsustainable development path. The World Bank has dubbed this indicator *adjusted net saving* or *genuine saving* (see, e.g., Hamilton, 2000). Genuine saving measures the rate of saving in an economy after taking into account pollution, depletion of natural resources, and investment in human capital. We illustrate a modified version of this concept in Figure 14. Define genuine capital accumulation (GKA) as the value of produced capital accumulation, $p_K\dot{K}$, plus natural capital accumulation, $p_N\dot{K}_N$. This is equivalent to capital accumulation minus natural capital depletion. Combining the pattern of produced capital accumulation from neoclassical growth theory with the NRKC discussion in section "Natural Resources Kuznets Curve Theory," note that GKA grows faster than produced capital accumulation after T'.

Figure 14. Capital, Natural Capital, and Genuine Capital Accumulation



Genuine Capital Accumulation: Empirics

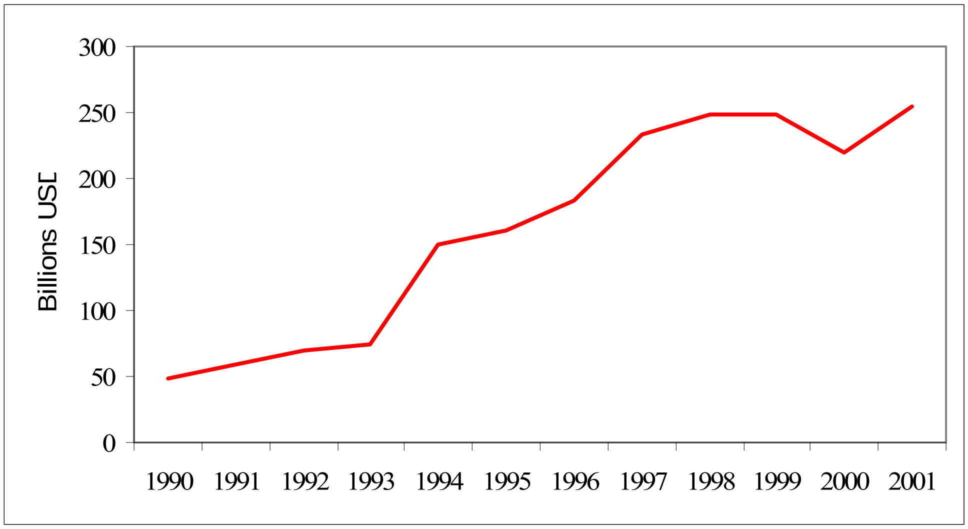
Using the World Bank data from the previous sections, we develop an estimate of China's GKA from 1990 to 2001. As evident in Table 11, GKA has been increasing over time, suggesting that the country's growth is not unsustainable. Figure 15 illustrates this acceleration.

Table 11. *Genuine Capital Accumulation, 1990–2001*

1990	$48.6
1991	$58.6
1992	$69.0
1993	$74.5
1994	$150.1
1995	$160.6
1996	$184.1
1997	$233.9
1998	$248.4
1999	$248.6
2000	$218.9
2001	$254.4

Note: Values are in billion U.S. dollars.

Figure 15. Genuine Capital Accumulation, 1990–2001



POLICY ENVIRONMENT

After ignoring the environmental consequences of economic policy decisions during the period of Mao Zedong's leadership (Shapiro, 2001), China's government became somewhat more vigilant about environmental regulation in the 1990s. The SEPA was established in 1998, and environmental laws and regulations began to appear shortly after its establishment.

Since then, China's environmental policies have evolved largely in response to domestic events (e.g., sandstorms in Beijing, the 1998 Yangtze floods, growing realization of health problems related to air pollution) and to China's growing involvement in international environmental diplomacy (e.g., the ratification of the Montreal Protocol). Attention has also been increasing due to a domestic environmental movement, including growing environmental concerns among China's urban elites, many of whom are keenly aware that Chinese environmental conditions lag behind the norm in urban areas in more developed nations.

The main regulatory framework to date is command and control, with SEPA issuing regulations, sending inspectors to check on implementation, and imposing fines on violators. These regulations include discharge limits based on both total emissions and ambient concentrations of emissions. New manufacturing enterprises are required to receive certification before production can begin, and time limits are set for compliance of existing enterprises. These regulations are far from consistent across firms, with enforcement typically focusing on large firms and often neglecting small-scale enterprises, especially TVEs located in rural areas. This in part reflects the tendency of officials to overlook pollution from enterprises that support local economies with jobs and tax revenue.

There are significant difficulties with enforcement, due in part to local government incentive structures geared to emphasize growth. Local officials sometimes prevent inspectors from completing their work or pay them to overlook violations. In other instances, local officials evade orders to close down polluting plants. For example, when the three-year "zero-hour operation" to clean up the Huai River targeted small factories along the river beginning in 1998, local officials sought to keep plants running by amalgamating small mills into larger units or by stopping daytime production but operating the plants at night. Similar problems surround efforts to compel factories to add pollution abatement facilities. One-third of such equipment operates only during inspections. One-third sit idle because managers see pollution abatement equipment as imposing excessive costs. Only the remaining third are operating as required by regulation standards (Watson et al., 2000).

Firms may purchase waste treatment equipment in accord with requirements but neglect to install the equipment. A joint effort among Massachusetts Institute of Technology (MIT), Qinghua University, and the Swiss Federal Institutes of Technology to improve boiler efficiency begun in over 200 sites in Henan, Jiangsu, and Shanxi provinces initially failed, despite developing a number of well-tailored and inexpensive measures for the various boiler sites. The MIT-led team found that the plant directors had no immediate incentive to upgrade the technologies in their plants. The team then researched the linkage between pollution and local health costs to help persuade local officials of the project's importance (Watson et al., 2000). The Watson study also found that perceived additional cost causes many industries to disregard end-of-the-pipe technologies. Even if multinationals provide pollution-control equipment, Chinese firms may fail to respond because the cost of installing and operating these devices is much higher than the financial penalty they might suffer for exceeding pollution limits.

Despite such difficulties, there is evidence that environmental incentive systems have reduced pollution discharge intensities. Analysis of both provincial- and plant-level data on water pollution suggests that discharge intensities are highly responsive to variations in provincial levies (Wang and Wheeler, 2003, 2005). Similarly, Wang (2002) shows that plant-level expenditures on end-of-pipe wastewater treatment are strongly responsive to pollution charges. The pollution charge system has been in place for over twenty years. The main problem is that the charges are too low. If prices were increased, the response would probably deliver a significant reduction in the total quantity of pollution.

However, other command and control regulations such as enforcement and environmental zoning appear to have little impact on abatement expenditures. Inspections, rather than pollution levies, are found to have a significant effect on firm-level environmental compliance (Dasgupta et al., 2001).

In a 2003 empirical study, Wang et al. examine the determinants of environmental enforcement (Wang et al., 2003). The authors analyze the determinants of firms' relative bargaining power with local environmental authorities in connection with the enforcement of pollution charges. Results from the study suggest that private-sector firms have less bargaining power than state-owned enterprises and that firms facing adverse financial situations have more bargaining power and tend to pay relatively smaller pollution charges. The greater the social impact of a firm's emissions, the less bargaining power it has with local environmental authorities.

Further difficulties arise from poor coordination between environmental policies and other official measures that affect the behavior of plant operators and other resource users. In particular, China has been very slow to break out of a long tradition of low pricing for electricity, water, wastewater treatment, and, more recently, gasoline. This encourages excess use of water, coal, and other resources and discourages recycling, all of which may have negative consequences for efforts to reduce effluents and improve ambient air and water quality.

SEPA is pushing to expand public disclosure of environmental performance as a means of directing public attention to severe pollution problems that persist despite the application of traditional regulatory instruments (Wang et al., 2004; Wang and Wu, 2004). Since 1998, SEPA has worked to establish GreenWatch, a public disclosure program for polluters. Adopted from a program in Indonesia, the GreenWatch rates firms' environmental performance from best to worst in five colors – green, blue, yellow, red, and black – and publicizes these ratings through the media. In 2000, pilot programs were implemented in Zhenjiang (Jiangsu) and Hohhot (Inner Mongolia). Reaction to the programs has been positive, leading Jiangsu Province to expand implementation to the entire province in 2001. SEPA is currently preparing for nationwide implementation of public disclosure.

Experimentation with new economic incentives includes noncompliance fines, consumer subsidies for energy-saving products, discharge permits, sulfur emission fees, and emissions trading. Select provinces and cities allowed trading of sulfur emission rights since 1997. There has also been a concerted effort to decentralize pollution by moving major effluent sources – most notably, Beijing's Capital Steel complex – away from urban centers.

Recent developments in the policy arena include a ban on leaded gasoline, stringent new emission requirements for cars, preparation for Beijing Olympics, escalating attacks on "growth at any cost" and "extensive growth," and strong emphasis by top leaders on "quality" growth and on reducing the social costs of economic development. All of this suggests that environmental issues may begin to get the high-level priority that seems essential to addressing some of the incentive issues and policy conflicts mentioned earlier.

CONCLUSION

Despite disparaging reports, the available figures show that China's growth is sustainable. Nonetheless, opportunities for improving environmental and natural resource management and accounting practices abound. After years of neglect, environmental issues have attracted growing attention within China's economic policy community. Although many regulations have been initiated, numerous opportunities remain for aligning private incentives with the public interest, especially on an ecosystem level.

With respect to air pollution, available statistics suggest that China has passed the flat part of the EKC for two of three major pollutants, consistent with its expected progress at current per capita income. Available measures show some improvement in urban air quality, in part because of decentralization of industry away from the pollution receptors, which remain clustered in the traditional industrial areas. Significant decreases in pollution per unit of output are offset by rapidly increasing industrial production. Despite considerable effort, there has been less success in controlling water pollution.

One might surmise from popular accounts of pollution and resource depletion that GNNP, a more accurate indicator of economic welfare, must lag far behind traditional measures of economic performance, such as NNP. In reality, our partial adjustments suggest that GNNP for most of the last two decades has grown slightly faster than NNP. Even allowing for serious problems of water scarcity and water pollution, the possibility of increased air pollution outside of the urban core, and a devalued forest stock, future efforts to compile more comprehensive environmental accounts are unlikely to show that GNNP is growing noticeably slower than NNP. This is largely because the wedge between the two measures is small and swamped by other components of growth. Nor is China's growth unsustainable. Indeed, its GKA is large and accelerating.

Despite China's impressive record of environmentally adjusted economic growth and GKA, many challenges remain. Perhaps the most serious concerns increasing water scarcity, especially in urban areas in the North, and the nationwide decline in water quality. In the past, China has successfully increased available water resources by building storage and delivery infrastructure. This strategy is not sustainable, due to the declining natural limits on exploitable water sources and increasingly costs of tapping the limited unexploited sources. Despite these difficulties, abundant opportunities for reducing waste through demand management remain, thus exemplifying the common belief that the Chinese character for crisis embeds the character for opportunity.

Similarly, while China has recorded substantial progress in decentralizing pollution control, substantial opportunities remain. Weaknesses in public administration, for example, have limited the impact of initial forays into emission-permit trading. Any scheme of fines, levies, or permits is only as strong as its implementation. In China today, inspectors are often unable or unwilling to impose effective controls. Measuring the declining quantity and quality of China's water resources remains an important task for future research.

Reforms are also needed to improve environmental accounting. For example, efficient air pollution control requires not only monitoring the quantities and types of emissions but also distinguishing them according to damages by receptor–source. Sampling protocols and indexing of pollution according to health risks are also needed. Similar challenges surround the measurement of natural resource depreciation, especially accounting for the changing composition and value of resource stocks.

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