

Rise of the Automobiles: the costs of increased NO₂ pollution in China's changing urban environment

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China's rapidly growing motor vehicle fleet is changing the makeup of its urban atmosphere. While the two major problem pollutants historically have been particulates and sulfur dioxide, the growth in the number of automobiles has generated substantially increased levels of nitrogen dioxide (NO₂). This paper examines and values the mortality health effects (reduced premature deaths) from cleaning up these three pollutants. Findings indicate that valued gains from reduced air pollution mortality can average 3% of a city's GDP. Moreover, the growing auto fleet may generate a ten-fold increase in NO₂-based mortality costs and offset other, ongoing cleanup efforts in many Chinese cities. Specifically, the paper explores how the increasing number of automobiles might diminish or offset environmental cleanup activities focused upon particulate and sulfur dioxide pollution.

The problem of urban air pollution in China is readily obvious to even the most casual observer or itinerant visitor, and this problem is especially severe by international standards. Several different sources indicate that a number of China's cities rank amongst the world's worst.¹ A deeper examination indicates that China's pollution problems have existed for a number of years and are likely to persist into the future as public concerns over the environment are tempered by a desire for economic growth.²

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1. R. L. Edmonds, 'The environment in the Peoples Republic of China 50 years on', *China Quarterly* no. 159, (September 1999), pp. 640–650; and K. He, H. Hou and Q. Zhang, 'Urban air pollution in China: current status, characteristics, and progress', *Annual Review of Energy and the Environment* 27, (2002), pp. 397–431 both refer to listings of Chinese cities amongst the world's most polluted cities.

2. Extended discussion on the persistent nature of China's pollution can be found in J. Bannister, 'Population, public health, and the environment in China', *China Quarterly* no. 156, (December 1998), pp. 986–1015; V. Smil, 'China's energy and resource uses: continuity and change', *China Quarterly* no. 156, (December 1998), pp. 935–951; and E. B. Vermeer, 'Industrial pollution in China and remedial policies', *China Quarterly* no. 156, (December 1998), pp. 952–985; R. Lotspeich and A. Chen, 'Environmental protection in the People's Republic of China', *Journal of Contemporary China*, 6, (March 1997), pp. 33–60. Surveys indicating increased environmental concern while sustaining economic concerns are found in Y. Wang, *China's Economic Development and Democratization* (Aldershot, England and Burlington, VT: Ashgate, 2003) and K. Wong, 'The environmental awareness of university students in Beijing, China', *Journal of Contemporary China* 12, (August 2003), pp. 519–536.

At the same time, the rapid Chinese policy-driven shift to automobiles is changing the makeup of the urban atmosphere. Auto emissions, which were an unforeseen problem in the early 1990s, are now a rapidly growing urban air pollution problem.³ In particular, the increase in the automobile fleet is adding significant amounts of a third major pollutant, nitrogen dioxide (NO₂), to the two *traditional* problem pollutants, particulates (TSP or PM₁₀) and sulfur dioxide (SO₂).

In spite of the persistence and relative severity of China's urban air pollution problems, general analysis and quantification of the potential gains to successful cleanup activities is limited, and inclusion of the effects of a growing vehicle fleet is entirely missing. In part, this missing analysis grows out of the interdisciplinary aspects of pollution research. The health literature linking pollution to health effects in China has been limited until very recently.⁴ Economic valuation of health outcomes in China is also very recent, and the detailed reporting of air pollution data in Chinese cities, which only began in the late 1990s, varies in the frequency of updates, is sometimes incomplete, and is occasionally inaccessible.⁵ As a result, most recent examinations of Chinese air pollution either focus only upon one city or extrapolate from one city across the entire country.⁶ Moreover, because research establishing the link between NO₂ pollution and health outcomes in China postdates most existing China studies, most previous works exclude NO₂ effects, focusing upon either particulates and SO₂ or particulates only.⁷

The rapid increase in China's motor vehicle fleet and its accompanying increases in NO₂ pollution, coupled with the medical literature's recent development of links

3. General observations are given in World Bank, *China: Air, Land, and Water* (Washington, DC: World Bank 2001); and L. Gan, 'Globalization of the automobile industry in China: dynamics and barriers in the greening of the road transportation', *Energy Policy* 31, (2003), pp. 537–551. Specific city observations can be found in S.-H. Ye, W. Zhou, J. Song, B.-C. Peng, D. Yuan, Y.-M. Lu and P.-P. Qi, 'Toxicity and health effects of vehicle emissions in Shanghai', *Atmospheric Environment* 34, (1999), pp. 419–429; L. Fu, J. Hao, D. He, K. He and P. Li, 'Assessment of vehicular pollution in China', *Journal of Air & Waste Management Association* 51, (2001), pp. 658–668; and B. Chen, C. Hong and H. Kan, 'Exposures and health outcomes from outdoor air pollutants in China', *Toxicology* 198, (2004), pp. 291–300.

4. Bannister, 'Population, public health, and the environment in China'.

5. He *et al.*, 'Urban air pollution in China', state that weekly air quality reports began in June 1997 and were replaced by daily reports in June 2000. V. Brajer and R. W. Mead, 'Valuing air pollution mortality in China's cities', *Urban Studies* 41, (2004), pp. 1567–1585, manage to obtain annual pollution data for 38 cities over a three year span from a number of different Chinese sources but find that local environmental reports are only sporadically available or updated. Even the daily pollution numbers posted and archived on the State Environmental Protection Agency's (SEPA) website are the pollution index numbers for only the most serious pollutant for that particular day.

6. The World Bank, *Clear Water, Blue Skies: China's Environment in the New Century* (Washington, DC: World Bank, 1997) assumes that 1995 pollution levels in Beijing are representative and applies them to the entire urban population. Single city studies have been done for Beijing by V. Brajer and R. W. Mead, 'Blue skies in Beijing? Looking at the Olympic effect', *Journal of Environment and Development* 12, (2003), pp. 239–263; for Shijiazhuang by C. Peng, X. Wu, G. Liu, T. Johnson, J. Shah and S. Guttikunda, 'Urban air quality and health in China', *Urban Studies* 12, (2002), pp. 2283–2299; and for Shanghai by H. Kan, B. Chen, C. Chen, Q. Fu and M. Chen, 'An evaluation of public health impact of ambient air pollution under various energy scenarios in Shanghai, China', *Atmospheric Environment* 38, (2004), pp. 95–102, H. Kan and B. Chen, 'Particulate air pollution in urban areas of Shanghai, China: health-based economic assessment', *Science of the Total Environment* 322, (2004), pp. 71–79; and J. Li, S. K. Guttikunda, G. R. Carmichael, D. G. Streets, Y.-S. Chang and V. Fung (2004) 'Quantifying the human health benefits of curbing air pollution in Shanghai', *Journal of Environmental Management* 70, (2004), pp. 49–62.

7. World Bank, *Clear Water, Blue Skies*, uses both particulates and SO₂. Single city studies by Peng *et al.*, 'Urban air quality and health in China', Kan *et al.*, 'An evaluation of public health impact', Kan and Chen, 'Particulate air pollution in urban areas', and Li *et al.*, 'Quantifying the human health benefits' include only particulates in their analysis.

between health problems and NO₂, suggest that significant effects of NO₂ pollution in China are being overlooked. Moreover, health gains from current cleanup efforts focused on particulates and SO₂ may, in fact, be mitigated by the increased auto fleet. Hence, several policy questions arise: first, what are the overall air pollution costs; second, what are the potential costs specific to increased NO₂; and finally, what magnitude of increase in auto-related NO₂ pollution will *offset* the cleanup gains from current, ongoing efforts focused on particulates and SO₂? These three questions comprise the focus of our study here.

Specifically, this paper seeks to develop a more complete assessment of the benefits of reducing China's urban air pollution and the impact of a rapidly growing motor vehicle pool. It explores the potential economic benefits of cleaning up the urban airshed using an interdisciplinary approach to quantify and value reductions in air pollution-related deaths (mortality cases) from lowering particulates, SO₂, and NO₂ in 49 Chinese cities.⁸ In particular, this study integrates knowledge and methods from both the health sciences and economics to determine and value the numbers of deaths which can be avoided from cleanup of these three pollutants. First, China-based health effects studies and economic valuation studies are used to project and value the number of averted deaths for two different scenarios of lowered levels of air pollution.⁹ Then, to isolate the impact of the swelling auto fleet, the number of additional deaths which may occur if only NO₂ pollution grows are projected. Finally, the paper estimates the rate of growth in NO₂ which would offset projected cleanups of particulates and SO₂. We begin by first discussing the data.

Data

In order to explore the impact of air pollution on a broad cross section of urban China, the analysis uses pollution data from 49 Chinese cities. For most of the cities, 2002 pollution information was collected by local municipal authorities and then published by China's environmental protection bureau.¹⁰ Since the health functions used in this analysis are based upon total suspended particulates (TSP), but most current pollution levels are reported as particles measuring less than 10 microns in diameter (PM₁₀), a PM₁₀ to TSP conversion ratio of 0.6 is used in those cities reporting PM₁₀ pollution.¹¹ The pollution levels for the three pollutants (TSP, SO₂, and NO₂) are shown in Table 1. A quick glance at the pollution data shows that the most prevalent

8. In contrast, some other health studies such as R. Mead and V. Brajer, 'Protecting China's children: valuing the health impacts of reduced air pollution in urban China', *Environment and Development Economics*, 10, (2005), pp. 745–768, focus on morbidity (illness) outcomes, ranging from simple cases of colds and sore throats, to respiratory hospital admissions and cases of chronic bronchitis.

9. This process parallels Brajer and Mead, 'Valuing air pollution mortality in China's cities' in their discussion of the seasonal nature of Chinese air pollution, but we need to generate our own results here in order to isolate the relative costs of NO₂ pollution. In doing so, we note a couple of key differences in this study. First, we use a different, larger, and more recent sample of Chinese cities. Second, Brajer and Mead rely on Hong Kong-based epidemiological studies for NO₂ mortality instead of the Shanghai-based studies used here.

10. China Environmental Protection, *Annual Report on Urban Environmental Management and Comprehensive Improvement of 47 Environmental Protection Key Cities*. English version available online at: <http://www.zhb.gov.cn/english/report/47cities-2002.htm> (accessed 15 June 2004). For two additional cities (Maanshan and Pingxiang), 2002 pollution figures were obtained from the municipal environmental protection bureau websites. Annual reports for these two cities are available at: <http://pxepb.gov.cn>><http://www.ahmasepa.gov.cn> and <http://pxepb.gov.cn> (accessed 25 May 2004).

11. These are the ratios used in World Bank, *China: Air, Land, and Water*, and World Bank, *Clear Water, Blue Skies*.

Table 1. Pollution and population levels by city

City	SO ₂ (µg/m ³)	TSP (µg/m ³)	NO ₂ (µg/m ³)	Population
Beihai	7	75	10	430,916
Beijing	68	276.67	76	11,311,400
Changchun	9	178	23	7,112,900
Changsha	97	231.67	39	5,917,100
Chengdu	51	201.67	46	10,279,300
Chongqing	91	255	38	11,309,500
Dalian	35	151.67	23	5,589,800
Fuzhou	15	125	39	5,988,200
Guangzhou	58	145	62	7,182,100
Guilin	25	63.33	28	603,500
Guiyang	98	175	22	3,384,500
Haikou	8	51.67	13	606,700
Hangzhou	51	206.67	52	6,341,000
Harbin	42	220	54	9,485,100
Hefei	10	196.67	29	4,456,400
Hohhot	36	411	41	2,135,000
Jinan	54	218.33	40	5,734,800
Kunming	27	165	37	4,913,600
Lanzhou	93	663	56	2,988,500
Lhasa	3	240	28	140,000
Lianyungang	35	201.67	21	700,000
Maanshan	21	176.67	30	1,214,500
Nanchang	63	191.67	33	4,436,300
Nanjing	36	241.67	38	5,574,000
Nanning	52	108.33	32	2,968,800
Nantong	41	191.67	33	780,250
Ningbo	21	108.33	56	5,476,300
Pingxiang	8	313	38	1,794,000
Qingdao	54	161.67	26	7,161,000
Qinghuangdao	46	133.33	24	2,664,900
Shanghai	36	181.67	58	13,375,900
Shantou	19	78.33	33	4,651,900
Shenyang	64	288.33	45	6,947,700
Shenzhen	18	101.67	50	4,724,500
Shijiazhuang	160	305	56	9,030,000
Suzhou	44	208.33	42	2,124,000
Taiyuan	129	295	37	3,177,900
Tianjin	69	230	46	9,211,800
Urumqi	116	434	58	1,703,600
Wenzhou	55	125	54	7,446,200
Wuhan	45	238.33	52	7,642,000
Xi'an	24	283.33	19	7,003,100
Xiamen	24	106.67	30	1,354,200
Xining	25	477	30	2,017,800
Yantai	39	128.33	25	1,614,000
Yinchuan	36	353	25	1,047,300
Zhanjiang	19	103.33	13	1,589,506
Zhengzhou	49	238.33	26	6,439,400
Zhuhai	26	78.33	40	1,262,700
Averages	45.96	210.86	37.27	
China standard	60	200	80	
WHO standard	50	90	40	

problem pollutant is TSP. Average TSP levels exceed the China standard and are more than double the WHO standard. SO₂ and NO₂ are on average relatively lower, but a number of cities continue to exceed Chinese and WHO standards. While average NO₂ levels are the lowest of the three pollutants listed, levels tend to be higher in larger, more prosperous cities. For example, the two cities with the highest levels of NO₂ pollution, Beijing and Guangzhou, are also two of the leading cities in terms of economic progress and have accumulated relatively large automobile fleets.

For the larger cities and provincial capitals, population numbers (also in Table 1) are taken from the 2002 annual statistical yearbook. For those cities not listed in the yearbook, the population numbers are found on the websites of the individual municipal governments. Because the cities included are driven by our ability to access the pollution data, they are neither totally random nor necessarily a representative sample. Still, they do include all of the provincial capitals and most of the other larger cities in China, and with a combined population of more than 231 million, they account for nearly half of China's reported urban population.

After obtaining pollution and population figures, the next step is to develop baseline mortality (non-accidental death) figures in order to apply the concentration–response health functions (described in the *health effect functions* section below).¹² A separate urban death rate stopped appearing in the annual statistical yearbooks after 1999. However, the ratio of the city death rate to the national average was relatively steady in every prior year we reviewed. Therefore, to derive a 2001 urban death rate, the 1999 city death rate ratio is applied to the 2001 national death rate. Finally, since deaths from the top 10 major diseases account for 92% of 2001 total urban deaths, 92% of our derived city death rate is used as the baseline mortality figure.¹³

Scenario construction

Having compiled the base pollution, population, and mortality data, the next step is to construct different scenarios of future pollution and population levels. Beginning with population, the analysis assumes an annual urban population increase of 0.7875% for the period 2002–2012, based on United Nations (UN) projections.¹⁴ While this projected increase is much lower than a 3.4% projected growth rate from the World Bank,¹⁵ we believe that this more conservative figure may more accurately reflect net population increases within our identified cities. In contrast, the World Bank's overall growth figure also includes rural–urban migration and the reclassification of some rural areas as urban and may not necessarily mean a net gain in population within a particular established city.

Next, for each of the three pollutants, there are three constructed scenarios. The first scenario, or the 'Business as Usual' (BAU) case, constitutes a baseline based upon 2002 pollution levels. For SO₂ and TSP, the projected BAU scenario keeps the

12. This is a standard approach in determining pollution costs. Brajer and Mead, 'Blue skies in Beijing?' and Brajer and Mead, 'Valuing air pollution mortality in China's cities' have used this methodology in their earlier China efforts.

13. All these values are found in the 2001 and 2002 statistical yearbooks. National Bureau of Statistics, *Zhongguo tongji nianjian* [China Statistical Yearbook] (Beijing: Zhongguo tongji chubanshe).

14. These are the numbers reported by G. K. Heilig, *Can China Feed Itself? A System for Evaluating Policy Options*, (1999). Available at the IIASA, International Institute for Applied Systems Analysis website: http://www.iiasa.ac.at/Research/LUC/ChinaFood/data/pop/pop_7.htm.

15. World Bank, *China: Air, Land, and Water*.

2002 levels constant. While China has trumpeted efforts to decrease pollution, there are several reasons to doubt the appearance of sudden, permanent decreases in pollution levels. First, several studies have forecast increased levels of pollution or emissions during the period of study.¹⁶ Second, recent cleanup successes may only apply to inner city areas and not to overall metropolitan areas.¹⁷ Third, an assertion that there has been some backsliding immediately following efforts to meet the Ninth Five-Year Plan (1995–2000) seems to be confirmed by a Chinese environmental report which observes declines in the percentage of cities reaching Chinese Grade II.¹⁸ Finally, we note that even Beijing, a standard bearer in pollution abatement because of the 2008 Olympics, has seen some backsliding, with 2002 levels for SO₂, NO₂, PM₁₀, and TSP all higher than their 2001 levels.¹⁹

Establishing the NO₂ BAU scenario is somewhat more complicated. Even though automobile use in China is increasing rapidly, the Tenth Five-Year plan (2001–2005) does not address NO₂ directly. Further, while Chinese motor vehicles are generally considered to be much more polluting than their developed country counterparts and frequently fail existing inspections,²⁰ China has announced the 2004/2005 implementation of new auto emissions standards.²¹ Acknowledging these new standards, this study estimates that NO₂ pollution will increase 7.6% annually for the BAU scenario, which is half of a projected 15.2% growth rate of automobiles in China.²² This vehicle growth rate

16. D. G. Streets and S. T. Waldhoff, 'Present and future emissions of air pollutants in China: SO₂, NO_x and CO', *Atmospheric Environment* 34, (2000), pp. 363–374; D. Van Vuuren, F. Zhou, B. de Vries, K. Jiang, C. Graveland and Y. Li, 'Energy and emission scenarios for China in the 21st Century—exploration of baseline development and mitigation options', *Energy Policy* 31, (2003), pp. 369–387; Li *et al.*, 'Quantifying the human health benefits'; and Kan and Chen, 'Particulate air pollution in urban areas'.

17. World Bank, *China: Air, Land, and Water*.

18. K. S. Betts, 'China's pollution progress slows', *Environmental Science and Technology* 36, (2002), pp. 308A–309A makes the assertion shortly after the completion of the Ninth Five-Year Plan. Subsequent supporting evidence suggesting some decline in environmental quality is from China Environmental Protection, *Report on the State of the Environment in China 2002, Atmospheric Environment*, (2003). English version available online at: <http://www.zhb.gov.cn/english/SOE/soechina2002/air.htm> (accessed 7 May 2004).

19. Beijing Environmental Protection Bureau, EPB, *2002 Nian Beijing shi huanjing zhuangkuang gongbao* [2002 Report on Environmental Conditions in Beijing], (2003). Available at the Beijing Environmental Protection Bureau website: <http://www.bjepb.gov.cn/newhb/html/hjgb/hjzkgb/2002gb.htm> (accessed 16 June 2003).

20. S. Stares and Z. Liu, 'Motorization in Chinese cities: issues and actions', in S. Stares and Z. Liu, eds, *China's Urban Transport Development Strategy: Proceedings of a Symposium in Beijing*, 8–10 November 1995, World Bank Development Paper No. 352, pp. 43–104; World Bank, *China: Air, Land, and Water*; Fu *et al.*, 'Assessment of vehicular pollution in China'; and B. Dolven, 'China. The environment—the great car crush', *Far Eastern Economic Review*, (dated 27 November 2003 and accessed electronically via Factiva) all note that Chinese vehicles are more polluting. Fu *et al.* also note the tendency to fail inspections.

21. Chinese media periodically mention forthcoming pollution standards. Two such announcements can be found in: 'Shanghai to adopt tougher auto emission standards', *China Daily*, (2003) [available at: http://www.chinadaily.com.cn/en/doc/2003-01/29/content_153283.htm (accessed 24 June 2004)]; and 'Nation sets to put brakes on auto industry', *China Daily*, [available at: http://www1.chinadaily.com.cn/en/doc/2003-09/10/content_262847.htm (accessed 28 October 2003)].

22. The projected auto growth rate is from the Development Research Center under the State Council and is reported in 'Car market hits high gear', *Asia Times*, (22 January 2002) [available at: <http://www.atimes.com/china/da22ad03.html> (accessed 5 March 2002)]. We assume that emissions will increase at half the auto growth rate because the announced move from Euro I to Euro II standards stipulates a 48% reduction in combined hydrocarbon and NO_x emissions for passenger cars and most commercial vehicles. (Required reductions from diesel engines are generally smaller.) Absent of any systematically quantifiable information on driving patterns, we implicitly assume that an increase in the number of automobiles leads to an equivalent increase in miles driven and emissions. However, anecdotal evidence from some cities and H. Zhou and D. Sperling, 'Traffic emission pollution sampling and analysis on urban streets with high-rising buildings', *Transportation Research Part D* 6, (2001), pp. 269–281, suggest that urban traffic jams lead to a decrease in miles driven but increased emissions as vehicles idle in traffic.

is consistent with a number of forecasts, studies, and historical patterns placing projected growth rates between 10 and 29%, yet it is still conservative in light of very recent trends.²³ Finally, we note that given Beijing's 7% increase in NO₂ pollution in 2002, despite even more stringent auto emissions standards, this 7.6% increase seems plausible.²⁴

With the BAU cases established, two additional scenarios then look at the benefits of successful pollution cleanup efforts. The first scenario considers cleanup efforts that lower pollution levels to the Chinese clean air standards: 200 µg/m³ for TSP, 60 µg/m³ for SO₂, and 80 µg/m³ for NO₂. The decline is assumed to be linear over the 2002–2013 period, much in the nature of a straight-line depreciation. Second, with the World Health Organization (WHO) publishing even more stringent standards intended to identify threshold levels at which adverse effects begin to appear, a second scenario considers meeting these standards: 90 µg/m³ for TSP, 50 µg/m³ for SO₂, and 40 µg/m³ for NO₂. For both TSP and SO₂, the analysis again projects linear declines from their 2002 levels to the targeted standards in 2012. For NO₂, the projected cleanup begins when the BAU NO₂ levels exceed the targeted standards.

Developing health effect functions

This section describes the development of concentration–response health functions, which link a particular health outcome to changes in air pollution. In past research, some international and China reports have relied on extrapolations from US studies.²⁵ However, the appropriateness of such extrapolations is somewhat questionable for a number of reasons, including basic cultural factors and differing perceptions of illness.²⁶ In fact, some studies go so far as to state that extrapolations from US studies to developing countries 'are likely to be misleading'.²⁷ This study avoids these issues by using China-based health studies only, which are described below.

The basic equation form used in our projections is that of the natural exponential function, as developed in the US EPA Retrospective Analysis, which evaluates the

23. Studies placing historical and projected vehicle growth rates in the range between 10 and 29% include Ye *et al.*, 'Toxicity and health effects of vehicle emissions in Shanghai'; Fu *et al.*, 'Assessment of vehicular pollution in China'; and World Bank, *China: Air, Land, and Water*. Other, recent news media reports of historical patterns include 'Nation sets to put brakes on', *China Daily*; Dolven, 'China. The environment—the great car crush'; M. Dorgan, 'An emerging auto market: great leap of China', *Detroit FreePress*, (13 March 2003) [available online at: http://www.freep.com/money/autonews/china13_20030313.htm (accessed 17 June 2003)]; and E. Baculinao, 'Engines revving as China goes car crazy', *NBC News*, (2004) [available online at: <http://www.msnbc.com/id/517580/> (accessed 15 June 2004)]. Recently reported sales for the past couple of years have covered a wider range of increases, approaching 80% or more. Some of these recent reports include 'Nation sets to put brakes on', *China Daily*; Baculinao, 'Engines revving as China goes car crazy'; and C.-C. Ni, 'China's new love of cars can be a fatal attraction', *Los Angeles Times*, (22 May 2004) (available online at: <http://www.latimes.com/la-fg-cars22may22,1,2999222.story>).

24. See Beijing Environmental Protection, *2002 Report on Environmental Conditions in Beijing*.

25. Two international examples are A. Krupnick, K. Harrison, E. Nickell and M. Toman, *The Benefits of Ambient Air Quality Improvements in Central and Eastern Europe: A Preliminary Assessment*, Resources for the Future discussion paper #ENR93-19 (Washington, DC: Resources for the Future, 1993); and B. D. Ostro, *Estimating the Health Effect of Air Pollutants: A Method with an Application to Jakarta*, World Bank Policy Research Working Paper #1301 (Washington, DC: World Bank, 1994). Many previous China studies including World Bank, *Clear Water, Blue Skies*; Peng *et al.*, 'Urban air quality and health in China'; Kan *et al.*, 'An evaluation of public health impact'; Kan and Chen, 'Particulate air pollution in urban areas'; and Li *et al.*, 'Quantifying the human health benefits' also use international health studies to varying degrees in their China focused studies.

26. A. Alberini and A. Krupnick, 'Air pollution and acute respiratory illness: evidence from Taiwan and Los Angeles', *American Journal of Agricultural Economics* 79, (1997), pp. 1620–1624.

27. M. L. Cropper, N. B. Simon, A. Alberini, S. Arora and P. K. Sharma, 'The health benefits of air pollution control in Delhi', *American Journal of Agricultural Economics* 79, (1997), pp. 1625–1629.

health benefits of emissions controls imposed by the Clean Air Act.²⁸ Specifically, our health effect calculations rely on the following functional form:

$$\Delta C = C(e^{b\Delta P} - 1)$$

where ΔC is the predicted change in total deaths, C is the baseline (existing) number of deaths, ΔP is the change in the pollution level, and b is an exponential 'slope' factor. This ' b ' is calculated from relative risk (RR) factors, or odds ratios, which are reported in the various China-based health studies consulted. These risk factors relate changes in pollution levels to the increased odds of dying prematurely. More specifically, the ' b ' is derived from the concentration–response functions in the following manner:

$$b = [\ln(\text{odds ratio})]/(\text{Change in Pollutant}).$$

For example, a reported odds ratio of 1.02 for a 100 microgram change per cubic meter ($\mu\text{g}/\text{m}^3$) in the amount of measured air pollution generates a ' b ' value as follows:

$$b = \ln(1.02)/100 \quad b = 0.000198.$$

Continuing the example, suppose then that the pollution level is expected to fall by, say, 10 ($\mu\text{g}/\text{m}^3$) due to a successful cleanup program. If the existing death rate (the baseline rate) is five deaths per 1,000 people, and the total population is 1 million, we would calculate the decline in number of deaths as follows:

$$\Delta C = (5/1,000) * (1,000,000)(e^{10 * 0.000198} - 1) = 9.9.$$

Thus, the successful cleanup program has averted ten deaths in the population.

TSP and SO₂ mortality

Over the past two decades, an extensive literature on TSP and SO₂ health effects has been established.²⁹ To develop TSP and SO₂ health equations for the 49-city data set, we rely on a study of air pollution and daily mortality in Shenyang, China.³⁰ Using Poisson regressions, the study authors regress the number of daily deaths against pollution and weather variables, along with indicators for Sundays and the previous day's mortality. Using the estimated coefficients from these regressions, the authors calculate relative risk (RR) factors for the two pollutants. In the case of SO₂, their estimated RR factor equals 1.0188, implying that the risk of all-cause mortality increases by 1.88% with a 100- $\mu\text{g}/\text{m}^3$ increase in SO₂. The corresponding RR factor for a 100- $\mu\text{g}/\text{m}^3$ increase in TSP is equal to 1.013. These relative risk factors for SO₂ and TSP generate concentration–response equation slope estimates (bs) of 0.000186 and 0.000129, respectively.

NO₂ mortality

Though the health literature connecting particulate and SO₂ exposures with premature death is rather well established, the associations between NO₂ exposures and mortality are much more recent. However, this literature is increasingly finding

28. US Environmental Protection Agency, *The Benefits and Costs of the Clean Air Act, 1970 to 1990* [Report] (Washington, DC: US EPA, 1997).

29. For a review of this literature, see *Ibid.*

30. Z. Xu, D. Yu, L. Jing and X. Xu, 'Air pollution and daily mortality in Shenyang, China', *Archives of Environmental Health* 55, (2000), pp. 115–120.

significant associations between NO₂ and various health outcomes in a number of different types of models. Most importantly for this study, these associations are being discovered in *multipollutant* mortality models.³¹ This latter finding is important because concentrations of NO₂ and particulates are often highly correlated, making the use of multipollutant models essential for disentangling the relative impacts of the different pollutants. To explain, in one study, it was found that NO₂ coefficient estimates derived from multipollutant equations can be as much as one-third the size of their single pollutant equation counterparts.³² To generate all of the benefit estimations, therefore, this study uses only results from multipollutant equations.

For NO₂ mortality, the analysis here relies on two recent studies that examine the health effects of air pollution in Shanghai from June 2000 to December 2001.³³ In each study, multipollutant regression results for NO₂, adjusted for the effects of PM₁₀ and SO₂, allow for the derivation of relative risk factors for non-accident mortality (RR = 1.012 and RR = 1.008 for the two studies). These factors are then converted, via the exponential concentration–response function, into slope estimates ($b = 0.00193$ and $b = 0.0007968$, respectively), which are then averaged, yielding a final ‘ b ’ value of 0.0009949.

Because studies linking NO₂ to health outcomes are still so new, we also compare our Shanghai-based derived ‘ b ’ used for this study with six other recent studies from various parts of the world. These studies generate a range of ‘ b ’ values from 0.0006 to 0.002267 and an average value of 0.00135.³⁴ Thus, the Shanghai-based results from which this study calculates its ‘ b ’ value fall in line with the evolving health literature for

31. P. Fischer, G. Hoek, B. Brunekreef, A. Verhoeff and J. Van Wijnen, ‘Air pollution and mortality in the Netherlands: are the elderly more at risk?’, *European Respiratory Journal* 21(Supplement 40), (2003), pp. 34s–38s; G. Hoek, B. Brunekreef, A. Verhoeff, J. Van Wijnen and P. Fischer, ‘Daily mortality and air pollution in the Netherlands’, *Journal of the Air & Waste Management Association* 50, (2000), pp. 1380–1389; S. Vedal, M. Brauer, R. White and J. Petkau, ‘Air pollution and daily mortality in a city with low levels of pollution’, *Environmental Health Perspectives* 111, (2003), pp. 45–51; C.-M. Wong, S. Ma, A. J. Hedley and T.-H. Lam, ‘Effect of air pollution on daily mortality in Hong Kong’, *Environmental Health Perspectives* 109, (2001), pp. 335–340; and T. M. Wong, W. S. Tam, T. S. Yu and A. H. S. Wong, ‘Associations between daily mortalities from respiratory and cardiovascular diseases and air pollution in Hong Kong, China’, *Occupational and Environmental Medicine* 59, (2002), pp. 30–35.

32. D. M. Stieb, S. Judek and R. T. Burnett, ‘Meta-analysis of time-series studies of air pollution and mortality: effects of gases and particles and the influence of cause of death, age, and season’, *Journal of the Air & Waste Management Association* 52, (2002), pp. 470–484.

33. H. Kan and B. Chen, ‘Air pollution and daily mortality in Shanghai: a time-series study’, *Archives of Environmental Health* 58, (2003), pp. 360–367; and H. Kan and B. Chen, ‘A case-crossover analysis of air pollution and daily mortality in Shanghai’, *Journal of Occupational Health* 45, (2003), pp. 119–124. The first study uses a time-series methodology, while in the second, the same authors employ a case-crossover approach to assess the association between various pollutants and daily mortality. The two studies differ in their basic methodologies: the time-series study follows an entire population under various exposure conditions, while the case-crossover design only considers affected parts of a population and their exposures relative to a typical, or baseline, level of exposure. Taken together, these two studies can provide a more robust estimate of the association between pollution and premature death than either method alone.

34. S. A. Bremner, H. R. Anderson, R. W. Atkinson, A. J. McMichael, D. P. Strachan, J. M. Bland and J. S. Bower, ‘Short term associations between outdoor air pollution and mortality in London 1992–4’, *Occupational and Environmental Medicine* 56, (1999), pp. 237–44; E. Cadum, G. Rossi, D. Mirabelli, M.A. Vigottie, P. Natale, L. Albano, G. Mardii, V. Di Meo, R. Cristofani, and G. Costa, ‘Air Pollution and Dairy Mortality in Turin, 1991–1996’, *Epidemiologia e Prevenzione*, 23, 1999, pp. 268–276 [Article in Italian]. ‘Air pollution and daily mortality in Turin’; W. H. Roemer and J. H. van Wijnen, ‘Daily mortality and air pollution along busy streets in Amsterdam, 1987–1998’, *Epidemiology* 12, (2001), pp. 649–653; Wong *et al.*, ‘Associations between daily mortalities from respiratory and cardiovascular diseases and air pollution in Hong Kong’; C.-M. Wong *et al.*, ‘Effect of air pollution on daily mortality in Hong Kong’; A. Zeghnoun, P. Czernichow, P. Beauudeau, A. Hautemaniere, L. Froment, A. Le Tertre and P. Quenel, ‘Short-term effects of air pollution on mortality in the cities of Rouen and Le Havre, France, 1990–1995’, *Archives of Environmental Health* 56, (2001), pp. 327–335.

NO₂-related mortality effects. At the same time, given the breadth of the range, this study again notes the importance of relying upon China-based work.

Developing economic values

Increased risk of premature mortality is one health effect long associated with exposure to SO₂, TSP, and, more recently, NO₂. Early attempts to value averted deaths relied on human capital accounting measures, which mainly consider lost future income. However, these measures provided an incomplete estimate of the loss to the individual and to society of reduced life expectancy, and economists thus moved toward a more comprehensive *willingness-to-pay* (WTP) measure. This measure can more completely capture the overall value of life by assessing the value groups of individuals place on reducing the probability of dying earlier than would otherwise be expected. The value of reduced annual risk of death, or of averted death, is a more accurate term for what is being measured, but the expression commonly used is *value of a statistical life* (VSL). A recent, comprehensive assessment of virtually all available US estimates from published WTP studies places most reported values of statistical life in the range of \$0.9 million to \$20.9 million, with the US EPA currently recommending \$6.2 million as their mid-range estimate for a VSL.³⁵

In contrast, relatively few studies have taken place in countries with significantly lower incomes. Transferring economic values to other countries has typically relied on a simple ‘scaling’ based on national per capita output (or income) ratios between the country of interest and the US, but such a procedure contains many drawbacks. The most obvious is the implicit assumption that preferences for health are similar across countries. Moreover, these preferences are assumed to be determined largely by income which ignores the potential influence of other cultural factors. Specifically, this assumption can be captured with an *income elasticity of willingness to pay* (α -WTP) for improved health that is equal to 1.0, implying that health is an income-neutral good.³⁶

Some recent valuation studies have begun to question these assumptions about income and preferences in developing countries. A Bangkok, Thailand study finds that the WTP for avoiding respiratory illness actually exceeds what would be predicted following a simple national income adjustment, suggesting that people may be viewing health as a basic necessity and ‘that those with lower incomes may be willing to pay a higher share of that income to protect their health’.³⁷ Elsewhere, two studies on health care valuation in urban areas in Taiwan reach similar conclusions.³⁸ More recently, another study derives a prediction function for developing countries, which accounts for differences in income, and

35. This assessment includes both market-based (hedonic) studies and survey-based (contingent valuation) studies. See C. Dockins, K. Maguire, N. Simon and M. Sullivan, *Value of Statistical Life Analysis and Environmental Policy: A White Paper for Presentation to Science Advisory Board—Environmental Economics Advisory Committee*, Final Report (National Center for Environmental Economics, US EPA, 2004).

36. With an income elasticity of one, if income were to increase by, say, 10%, so would the WTP for improved health.

37. L. G. Chestnut, B. D. Ostro and N. Vichit-Vadakan, ‘Transferability of air pollution control health benefits estimates from the United States to developing countries: evidence from the Bangkok study’, *American Journal of Agricultural Economics* 79, (1997), pp. 1630–1635.

38. A. Alberini and A. Krupnick, ‘Air quality and episodes of acute respiratory illness in Taiwan cities: evidence from survey data’, *Journal of Urban Economics* 44, (1998), pp. 68–92; and A. Alberini and A. Krupnick, ‘Cost-of-illness and willingness-to-pay estimates of the benefits of improved air quality: evidence from Taiwan’, *Land Economics* 76, (2000), pp. 37–53.

estimates an income elasticity of WTP ranging from 1.52 to 2.27 for averted mortality.³⁹ This, of course, implies that health (or life) is being considered to be a ‘luxury’ good, and that those with higher incomes are willing to pay a disproportionately higher share of that income to reduce the probability of premature death. In contrast, other studies calculating the health benefits of reducing ozone and particulates for Mexico City and the economic costs of particulate air pollution in Singapore use an α -WTP ranging from 0.40 to 0.32.⁴⁰ These lower values are consistent with the idea that a human life has an intrinsic value regardless of the level of income.

In contrast to these cross-country comparison studies, this work uses the first known major valuation study conducted in China, which employs contingent valuation (the survey approach) to value adverse health effects (including the value of a statistical life) in three diverse locations (Beijing City, Anqing City, and the rural areas near Anqing).⁴¹ Because this valuation study is China-based, it provides a starting point from which to develop VSL estimates for averted pollution mortality. Still, despite the fact that the study was conducted completely in China, we hesitate to rely solely upon the resulting values. By their own admission, the authors concede that some form of hypothetical bias (or respondent bias) may exist in the study. When respondents were offered risk reductions of different sizes as part of the contingent valuation questioning, there was no significant difference in their WTP responses.

Given the lack of quantitative evidence or definitive valuation in China, this study takes a hybrid approach to generate a range of potential values. First, it converts US values using national per capita output ratios, implicitly assuming an α -WTP of 1.0, to produce what becomes our high-range estimate for VSL. Thus, to convert from the US-based value of life estimates, we use the purchasing power parity based national output ratio between China and the US (11.71%) to generate an economic value for averted mortality. The resulting figure for our high end estimate is (\$6.2 million)*(0.1171) which equals \$726,000.⁴² To generate a low-end estimate, we turn to the China valuation study’s range of mean VSL, which extends from \$15,000 to \$178,000.⁴³ Averaging these provides a WTP estimate to avoid premature death of \$96,500. Finally, to generate a mid-range VSL, the low and high estimates are averaged, resulting in a value of \$411,000, which is consistent with an α -WTP of 1.27. Since the mean of the extremes of the α -WTPs in the various studies mentioned above—ranging from a high of 2.27 to a low of 0.32⁴⁴—is equal to 1.295, the mid-range value for VSL in this study appears to be a reasonable one. It should again be

39. B. J. Bowland and J. C. Beghin, ‘Robust estimates of value of a statistical life for developing economies’, *Journal of Policy Modeling* 23, (2001), pp. 385–396.

40. The Mexico City study is World Bank, ‘Improving air quality in metropolitan Mexico City: an economic valuation’, *Policy Research Working Paper*, WPS 2785 (2002) and uses the α -WTP of 0.40 for deriving its mid-range value of life. The α -WTP of 0.32 for Singapore is from E. Quah and T. L. Boon, ‘The economic cost of particulate air pollution on health in Singapore’, *Journal of Asian Economics* 14, (2003), pp. 73–90.

41. Y. Zhou and J. K. Hammitt, *The Economic Value of Air-pollution-related Health Risks in China: A Contingent Valuation Study*, Report prepared for the Center for Risk Analysis (Harvard School of Public Health, 2003).

42. The US and China GDP numbers were obtained from World Bank, *World Development Indicators Database* (Washington, DC: World Bank, 2001).

43. Zhou and Hammitt, ‘The economic value of air-pollution-related health risks in China’.

44. The high value is from Bowland and Beghin, ‘Robust estimates of value of a statistical life’. The low value is from Quah and Boon, ‘The economic cost of particulate air pollution on health in Singapore’.

noted that these values are not being ascribed to the life of any individual but to reducing the annual probability of death by a small amount.

Results and discussion

Total pollution mortality

Applying the China-based concentration–response functions to projected levels of pollution cleanup in the 49 cities, this study now predicts the number of statistical lives that would be saved if China were to successfully bring urban air pollution down to the two standards. Clearly, the benefits of pollution cleanup are substantial. In the WHO scenario projections made for 2003–2012, rising population levels, combined with reductions in pollution, result in a steadily increasing number of averted mortality cases. Over the ten-year period, these total over 423,000 deaths avoided with approximately 70% of these attributable to NO₂ (Table 2; Table 3 gives the values for the China scenario). The mid-range dollar value of this health improvement approaches \$175 billion in US\$2001 (Table 4), with low-end and high-end estimates of nearly \$41 billion and \$308 billion, respectively. Although the China scenario projections are only about two-fifths as large as the WHO scenario's, due to the assumed lower level of cleanup success, the overall results are still sizeable. Here, about 114,000 cases of premature mortality are averted, with a mid-range value of approximately \$47 billion. In this scenario, about 60% of the benefits are generated by NO₂ reductions.

To put these numbers in context, consider the 34-city subset of our dataset for which the annual yearbook includes 2003 localized GDP figures.⁴⁵ Using the mid-range value for averted deaths, we find that the estimated annual gains from effective pollution control to the WHO standard average approximately 3% of local GDP. Using mid-range values for the China standard case, the estimated gains still average nearly 1% of local GDP. Overall, the average estimated annual mid-value gains range from 0.38% of local GDP in a relatively clean city like Xiamen, to as much as 13.27% of local GDP for a relatively polluted city like Lanzhou.

Additional NO₂ deaths

Next, the analysis considers NO₂ pollution in two additional contexts. First, it estimates how many extra deaths will possibly be caused by rising NO₂ levels as opposed to maintaining current levels. In the previous section, the BAU case for NO₂ involves a 7.6% growth rate and is compared to meeting Chinese and WHO standards. Here, the difference between an NO₂ level growing at a rate of 7.6% and a constant level of NO₂ pollution (fixed at 2002 levels) is used to generate *additional* NO₂-related deaths. Table 5 presents these results, which total more than 246,000 additional statistical deaths from failing to maintain current NO₂ levels. Using the mid-range value of life, the mortality cost of this projected increase in NO₂ pollution is over \$105 billion.

These additional projected deaths and their associated costs are much greater than—more than double—the benefits of meeting Chinese standards for NO₂ but less

45. National Bureau of Statistics, *China Statistical Yearbook*.

Table 2. Averted deaths—pollution down to WHO standard

City	SO ₂	TSP	NO ₂	Total
Beihai	0	0	0	0
Beijing	1,112	8,056	37,559	46,727
Changchun	0	2,377	450	2,827
Changsha	1,522	3,192	5,965	10,679
Chengdu	56	4,364	15,391	19,811
Chongqing	2,536	7,112	10,789	20,437
Dalian	0	1,308	354	1,662
Fuzhou	0	794	6,037	6,831
Guangzhou	314	1,498	17,667	19,479
Guilin	0	0	184	184
Guiyang	889	1,093	106	2,088
Haikou	0	0	0	0
Hangzhou	35	2,814	11,767	14,616
Harbin	0	4,692	18,741	23,433
Hefei	0	1,807	1,407	3,214
Hohhot	0	2,631	2,564	5,195
Jinan	124	2,800	6,549	9,473
Kunming	0	1,399	4,073	5,472
Lanzhou	703	6,650	6,265	13,618
Lhasa	0	80	43	123
Lianyungang	0	297	14	311
Maanshan	0	400	484	884
Nanchang	315	1,714	2,555	4,584
Nanjing	0	3,220	5,317	8,537
Nanning	32	206	1,414	1,652
Nantong	0	301	449	750
Ningbo	0	380	11,480	11,860
Pingxiang	0	1,529	1,711	3,240
Qingdao	156	1,948	1,318	3,422
Qinghuangdao	0	438	280	718
Shanghai	0	4,658	29,657	34,315
Shantou	0	0	2,679	2,679
Shenyang	531	5,260	9,990	15,781
Shenzhen	0	209	8,201	8,410
Shijiazhuang	5,457	7,417	18,930	31,804
Suzhou	0	956	2,676	3,632
Taiyuan	1,377	2,488	2,634	6,499
Tianjin	956	4,910	13,793	19,659
Urumqi	611	2,252	3,777	6,640
Wenzhou	203	987	14,712	15,902
Wuhan	0	4,317	14,181	18,498
Xiamen	0	85	540	625
Xi'an	0	5,167	522	5,689
Xining	0	3,007	804	3,811
Yantai	0	234	206	440
Yinchuan	0	1,054	134	1,188
Zhanjiang	0	80	0	80
Zhengzhou	0	3,638	1,185	4,823
Zhuhai	0	0	1,442	1,442
Total	16,929	109,819	296,996	423,744

Table 3. Averted deaths—pollution down to China standard

City	SO ₂	TSP	NO ₂	Total
Beihai	0	0	0	0
Beijing	494	3,292	21,872	25,658
Changchun	0	0	0	0
Changsha	1,197	710	0	1,907
Chengdu	0	65	1,306	1,371
Chongqing	1,916	2,359	0	4,275
Dalian	0	0	0	0
Fuzhou	0	0	273	273
Guangzhou	0	0	6,336	6,336
Guilin	0	0	0	0
Guiyang	703	0	0	703
Haikou	0	0	0	0
Hangzhou	0	160	2,346	2,506
Harbin	0	718	4,047	4,765
Hefei	0	0	0	0
Hohhot	0	1,721	0	1,721
Jinan	0	398	0	398
Kunming	0	0	0	0
Lanzhou	539	5,346	1,697	7,582
Lhasa	0	21	0	21
Lianyungang	0	4	0	4
Maanshan	0	0	0	0
Nanchang	73	0	0	73
Nanjing	0	0	0	0
Nanning	0	880	0	880
Nantong	0	0	0	0
Ningbo	0	0	3,110	3,110
Pingxiang	0	771	0	771
Qingdao	0	0	0	0
Qinghuangdao	0	0	0	0
Shanghai	0	0	8,506	8,506
Shantou	0	0	0	0
Shenyang	152	2,331	764	3,247
Shenzhen	0	0	1,212	1,212
Shijiazhuang	4,958	3,604	5,129	13,691
Suzhou	0	67	85	152
Taiyuan	1,201	1,147	0	2,348
Tianjin	503	1,047	5,070	6,620
Urumqi	518	1,524	1,083	3,125
Wenzhou	0	0	3,177	3,177
Wuhan	0	1,110	2,827	3,937
Xiamen	0	0	0	0
Xi'an	0	2,216	0	2,216
Xining	0	2,141	0	2,141
Yantai	0	0	0	0
Yinchuan	0	610	0	610
Zhanjiang	0	0	0	0
Zhengzhou	0	935	0	935
Zhuhai	0	0	0	0
Total	12,254	33,177	68,567	113,998

Table 4. Valuation of averted mortality (billions of 2001 US dollars)

Scenario	Averted SO ₂ mortality	Averted TSP mortality	Averted NO ₂ mortality	Total
China standard				
Low value	\$1.183	\$3.202	\$6.617	\$11.001
Mid value	\$5.036	\$13.636	\$28.181	\$46.853
High value	\$8.896	\$24.087	\$49.780	\$82.763
WHO standard				
Low value	\$1.634	\$10.598	\$28.660	\$40.891
Mid value	\$6.958	\$45.136	\$122.065	\$174.159
High value	\$12.290	\$79.729	\$215.619	\$307.638

than—though still more than half—the number of averted deaths that could be obtained by meeting the WHO standard. The projected number of deaths from this scenario is relatively low because NO₂ levels are still relatively low in a number of cities. Of the 49 cities in this study, 21 do not initially have harmful levels of NO₂, but only two cities (Beihai and Haikou) do not reach such levels by 2013 in our projections. The potential costs of NO₂ pollution in China become especially apparent when we again look at the 34 city subset where we have localized urban GDP figures. In the initial year of our projections the value of NO₂-induced mortality is less than 0.15% of local GDP on average. In the final year, however, even after assuming that the local GDP annual growth will be 8%, our projections of the value of NO₂-induced mortality are slightly over 1.7% of local GDP on average, implying that the *relative* cost of NO₂ pollution increases more than ten-fold over the projected time horizon.

NO₂ offsets

The impact of increased NO₂ pollution is also apparent in the second additional context of our analysis. Because current Chinese cleanup efforts are aimed at SO₂ and particulates, we calculate the rate of annual NO₂ growth which will ‘offset’ the deaths averted by each city’s SO₂/TSP cleanup efforts (see Table 6). For example, in Beijing we predict that a 3.27% annual increase in NO₂ will lead to 9,168 additional deaths over the 2003–2012 study period. This rate of growth will completely negate, or offset, the averted mortality gains made by reducing SO₂ and TSP down to the WHO standard over the ten-year period. Offsetting the averted deaths resulting from reaching the China standard, in contrast, will require only a 1.44% annual NO₂ growth rate in Beijing.

In cities with either low initial NO₂ levels or very high levels of SO₂/TSP pollution (for example, Xi’an, which has high particulates, or Guiyang, which has both), a high rate of NO₂ growth is required to offset the health improvements related to SO₂ and TSP reductions. On the other hand, for cities with relatively high levels of NO₂ (such as Wuhan) or low levels of SO₂/TSP pollution (such as Fuzhou), a low rate of NO₂ growth will offset any gains from the current cleanup focus. In looking at the results, note that even the BAU scenario for NO₂ growth is sufficient to offset gains from SO₂ and TSP cleanup to the WHO standard for 27 out of 44 of the cities, including the

Table 5. Additional deaths arising from 7.6% annual increase in NO₂ pollution

City	Additional deaths
Beihai	0
Beijing	24,868
Changchun	526
Changsha	6,269
Chengdu	13,529
Chongqing	11,051
Dalian	414
Fuzhou	6,344
Guangzhou	12,815
Guilin	174
Guiyang	153
Haikou	0
Hangzhou	9,455
Harbin	14,697
Hefei	1,536
Hohhot	2,500
Jinan	6,549
Kunming	4,402
Lanzhou	4,806
Lhasa	40
Lianyungang	16
Maanshan	487
Nanchang	2,659
Nanjing	5,446
Nanning	1,573
Nantong	468
Ningbo	8,807
Pingxiang	1,753
Qingdao	1,351
Qinghuangdao	282
Shanghai	22,294
Shantou	2,788
Shenyang	8,942
Shenzhen	6,769
Shijiazhuang	14,521
Suzhou	2,549
Taiyuan	2,847
Tianjin	12,124
Urumqi	2,839
Wenzhou	11,538
Wuhan	11,394
Xiamen	545
Xi'an	563
Xining	812
Yantai	236
Yinchuan	153
Zhanjiang	0
Zhengzhou	1,215
Zhuhai	1,442
Total	246,541

Table 6. Rates of increase in NO₂ pollution necessary to offset projected TSP and SO₂ clean-up activity

City	Offset growth	
	China standard	WHO standard
Beihai	0.00%	0.00%
Beijing	1.44%	3.27%
Changchun	0.00%	11.28%
Changsha	2.99%	6.11%
Chengdu	0.05%	2.91%
Chongqing	3.83%	6.90%
Dalian	0.00%	9.69%
Fuzhou	0.00%	1.53%
Guangzhou	0.00%	1.34%
Guilin	0.00%	0.00%
Guiyang	9.96%	13.43%
Haikou	0.00%	0.00%
Hangzhou	0.17%	2.71%
Harbin	0.47%	2.86%
Hefei	0.00%	8.11%
Hohhot	5.61%	7.91%
Jinan	0.58%	3.86%
Kunming	0.00%	3.57%
Lanzhou	8.88%	10.47%
Lhasa	6.22%	9.87%
Lianyungang	6.93%	14.85%
Maanshan	0.00%	7.00%
Nanchang	2.44%	6.62%
Nanjing	2.15%	5.20%
Nanning	0.00%	3.73%
Nantong	0.00%	6.08%
Ningbo	0.00%	0.42%
Pingxiang	4.20%	6.89%
Qingdao	0.00%	8.65%
Qinghuangdao	0.00%	8.33%
Shanghai	0.00%	1.93%
Shantou	0.00%	0.00%
Shenyang	2.51%	5.33%
Shenzhen	0.00%	0.30%
Shijiazhuang	4.92%	6.91%
Suzhou	0.26%	3.30%
Taiyuan	6.66%	9.33%
Tianjin	1.21%	4.14%
Urumqi	5.82%	7.65%
Wenzhou	0.00%	0.98%
Wuhan	0.93%	3.34%
Xiamen	0.00%	4.28%
Xi'an	13.08%	16.67%
Xining	11.89%	14.11%
Yantai	0.00%	7.58%
Yinchuan	11.58%	14.37%
Zhanjiang	0.00%	13.84%
Zhengzhou	7.10%	0.11%
Zhuhai	0.00%	0.00%
Non-zero average	4.69%	6.54%

relatively developed major cities of Beijing, Shanghai and Guangzhou. For a cleanup to the China standards, the number of cities that will suffer a complete offset from the BAU scenario is 22 (out of 26 cities).⁴⁶ Clearly, the potential impact of automobiles and their NO₂ emissions is substantial.

Summary and conclusions

This paper explores the potential health benefits to China should extensive urban air pollution cleanup efforts be undertaken. By projecting decreases in the levels of several specific pollutants under two different cleanup targets, the paper estimates the number of statistical deaths averted. It then assigns dollar values to these cases and finds that the identified direct benefits are substantial.

The paper departs from previous studies in several important ways. First, it uses contemporary pollution levels from a wider spectrum of cities in China than has been used in previous work. Second, the inclusion of NO₂ pollution in the analysis gives a more comprehensive assessment of urban pollution consequences than most other studies. Finally, the paper is unique in exploring the dynamics of recent increases in NO₂ pollution as China's automobile fleet undergoes rapid expansion.

While the focus here is on premature deaths, we also acknowledge the potential existence of a number of relatively less serious morbidity, or illness, effects (such as respiratory hospital admissions and asthma). For example, a recent 38 city study of child morbidity effects in China reports cleanup benefits ranging from \$871 million to over \$6.2 billion.⁴⁷ Adult morbidity studies would generate additional gains. Moreover, some possible health outcomes are omitted entirely for either of two reasons. In some cases, there exist economic values for certain health effects, but the health link has not yet been established in China studies. For example, in the US, associations have been established between particulates and lost workdays and it is reasonable to assume that these same associations (to some degree) also exist in China. In other cases, China-specific health links are quantified, but economic values are lacking. For example, reduced lung function has been shown to be associated with air pollution in Beijing, but economists have yet to assign a dollar value to this condition.⁴⁸

In addition, while this analysis provides one estimate of pollution cleanup benefits, there are additional factors involved. The benefits and valuations provided here are based solely upon estimates for the years 2003–2012. Cleanup efforts involving long-term projects or permanent changes to lower pollution will almost certainly produce additional benefits beyond 2012. Moreover, China stands to gain from a number of non-health, pollution-related impacts—such as reductions in damage to ecosystems and materials as well as improvements in visibility—that would certainly be realized as part of successful cleanup efforts.

46. Here, the number of cities examined for offsets is smaller simply because when the Chinese standard is used, some of the cleaner cities record no SO₂ or TSP-related deaths to offset.

47. Mead and Brajer, 'Protecting China's children'.

48. X. Xu, D. W. Dockery and L. H. Wang, 'Effects of air pollution on adult pulmonary function', *Archives of Environmental Health* 46, (1991), pp. 198–206.

Finally, it is important to note that this valuation process is still in its infancy and that much work remains to be done. Advances in the health sciences have established links between air pollution and health outcomes as well as narrowed the bounds of uncertainty about some health effects. Similarly, there is progress being made in terms of how to economically value particular health effects. Still, there remain many questions within these ranges about where the *real* values lie. Hence, while the estimates presented here begin to measure the potential benefits of cleaner urban air in China, they should be viewed for what they are—estimates.

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