Lower Pollution, Longer Lives
Life Expectancy Gains if India Reduced Particulate Matter Pollution

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India's population is exposed to dangerously high levels of air pollution. Using a combination of ground-level in situ measurements and satellite-based remote sensing data, this paper estimates that 660 million people, over half of India's population, live in areas that exceed the Indian National Ambient Air Quality Standard for fine particulate pollution. Reducing pollution in these areas to achieve the standard would, we estimate, increase life expectancy for these Indians by 3.2 years on average for a total of 2.1 billion life years. We outline directions for environmental policy to start achieving these gains.

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1 Introduction

Air pollution is a global public health problem. The World Health Organization (WHO) declared air pollution the world's single largest environmental health risk and attributed around seven million deaths globally to air pollution in 2012.[1] The Global Burden of Disease 2010 report estimated that ambient particulate matter (PM) air pollution accounts for about 6% of global deaths (IHME 2013; Lim et al 2012).

Air pollution in India is severe. Data from the country's apex environmental regulator, the Central Pollution Control Board (CPCB), reveals that 77% of Indian urban agglomerations exceeded National Ambient Air Quality Standard (NAAQS) for respirable suspended particulate matter (PM_{10}) in 2010 (CPCB 2012).[2] Estimates from the WHO suggest that 13 of the 20 cities in the world with the worst fine particulate ($PM_{2.5}$) air pollution are in India, including Delhi, the worst-ranked city.[3] India has the highest rate of death caused by chronic respiratory diseases anywhere in the world.[4]

In this paper we estimate the life expectancy loss from fine particulate air pollution in India, and in doing so highlight air pollution as an urgent public health problem that deserves policy attention. These estimates provide one measure of "benefits" which can be used to conduct cost–benefit analyses of potential air pollution control policies in India.

Our analysis has three steps: (1) construction of a fine particulate air pollution data set at the district and city level; (2) identifying an appropriate estimate of the effect of particulate pollution on long-term mortality; and (3) applying the estimated relationship between air pollution and mortality to the air pollution data to calculate the life expectancy gains from reducing air pollution in all parts of the country to India's national air pollution standard.

We use the best available information on air pollution levels across India to construct our data set. We use ground monitoring data for the predominantly urban areas covered by the CPCB's air quality monitoring network. Where monitoring data is unavailable, we use new satellite-based estimates (Dey et al (2012) create satellite measures of fine particulates for the whole of India). The data show that both urban and rural populations are exposed to dangerously high levels of fine particulates ($PM_{2.5}$). Six hundred and sixty million people (54.5% of the population) live in regions that do not meet the Indian NAAQS for fine particulate matter, and nearly every Indian (1,204 million people, or 99.5% of the population) lives in a region with air pollution levels above the stricter guidelines of the WHO.

Within a given district, individuals may vary in their exposure to air pollution. However, as many air pollution action plans target specific districts, industrial clusters, or metropolitan areas, a focus on district and city averages is suitable for evaluating the benefits of a policy that is able to target and bring down district-average or city-average ambient air pollution.

Next, we identify an appropriate estimate of the effect of average ambient air pollution concentrations on life expectancy. The key concerns in estimating this relationship are twofold. First, air pollution and life expectancy may co-vary with a host of unobserved factors. This implies that the extent of correlation between these two variables may not provide an estimate of the causal impact of air pollution on life expectancy. Second, an individual's ability to limit his or her exposure to dirty air may vary with socio-economic status and available public amenities. Thus, a causal estimate would be applicable to India only if citizen's socio-economic status and available public amenities are comparable. Our preferred estimate is from a recent study using data from Chinese cities (Chen et al 2013). This paper, using a research design that separates the effect of pollution from other factors that also affect mortality, finds that an additional 100 micrograms per cubic metre ($\mu g/m^{3)}$ of total suspended particulates (TSPs) reduces life expectancy at birth by roughly three years.[5]

Finally, we apply this estimate to the Indian data to conduct a detailed health accounting exercise that estimates the loss of life expectancy in India from outdoor particulate matter pollution. We find that the 660 million people exposed to $PM_{2.5}$ pollution above the Indian NAAQS would gain an average of 3.2 years of life expectancy if air quality in these areas were improved to meet the national standards. Put another way, compliance with Indian air quality standards would save 2.1 billion life years. We show that these numbers remain broadly similar when using the estimated pollution–mortality relationship from other studies that are designed to investigate the impacts of sustained high ambient pollution on population outcomes.

The loss of more than two billion life years is a substantial price to pay for air pollution. And yet this may still be an underestimate of the costs of air pollution, because we do not account for the impact of other air pollutants, the impacts of particulates on morbidity or labour productivity, as well as preventive health or avoidance costs borne by Indian households.

We propose three policy responses to India's particulate problem. First, India should exploit advances in instrumentation to adopt continuous information systems for monitoring ambient concentrations and pollution from high-emitting industries. Increased monitoring can play an important role as a health advisory system and as a means of increasing pressure on polluters to comply with existing regulations. Second, we recommend a greater reliance on civil penalties in environmental law; this is a natural extension of the polluter pays principle, widely recognised in Indian law, and would provide an incentive to reduce pollution rather than evade regulation. Third, market-based mechanisms for environmental regulation can build on the first two policies, monitoring and the penalties for violations, to reduce pollution at the lowest possible cost. Market-based instruments have been used successfully to address a range of pollution problems in many other countries, and have been discussed, but never tried, in India.

The remainder of this paper is organised as follows. Section 2 describes how we estimate particulate concentrations and discusses pollution levels across the country. Section 3 briefly describes the scientific evidence relating fine particulates to mortality and carries out a calculation of the impact of high air pollution on life expectancy in India. Finally Section 4 concludes by discussing policy responses.

2 Estimating Particulate Air Pollution across India

First things first — what is particulate matter? PM is a type of air pollution, consisting of numerous tiny particles suspended in air. PM affects the cardiovascular and respiratory systems and has consistently been shown to be dangerous to human health. PM air pollution is called by different names, depending on the size of the particles. Box 1 lays out these various names, their relation to one another, and the standards that have been set by India and the WHO to designate maximum

Box 1: What Is Particulate Matter Air Pollution and What Air Quality Standards Apply to It?

"Particulate Matter" (PM) refers to small particles suspended in air, either solid or liquid droplets, and originating from various sources that pollute ambient air. Particulate matter is made up of different organic and inorganic components; the major constituents include acids (sulphate and nitrates), ammonia, sodium chloride, black carbon, water, and mineral dust. PM is widespread and affects more people than any other ambient air pollutant.[6]

Particulate matter adversely affects the cardiovascular and respiratory systems. The health impact of PM increases as particle size decreases. Thus PM is generally classified based on the size or coarseness of particles and that forms the basis for setting ambient air quality standards. The classification is presented below.

PM Classification

SPM/TSPs	"suspended particulate matter"/ "total suspended particulates"	particles of size < 100 μm
PM_{10}	"respirable particulate matter"	particles of size < 10 μm
$PM_{2.5}$	"fine particles"	particles of size < 2.5 μm

Globally, ambient air quality standards are set in terms of prescribed levels of annual and daily average concentrations of PM_{10} and $PM_{2.5}$. The prevailing Indian NAAQS-2009 adopts PM_{10} and $PM_{2.5}$ based standards, and discontinues the earlier SPM based NAAQS-1994 standards. The Indian NAAQS and WHO guidelines are presented below.

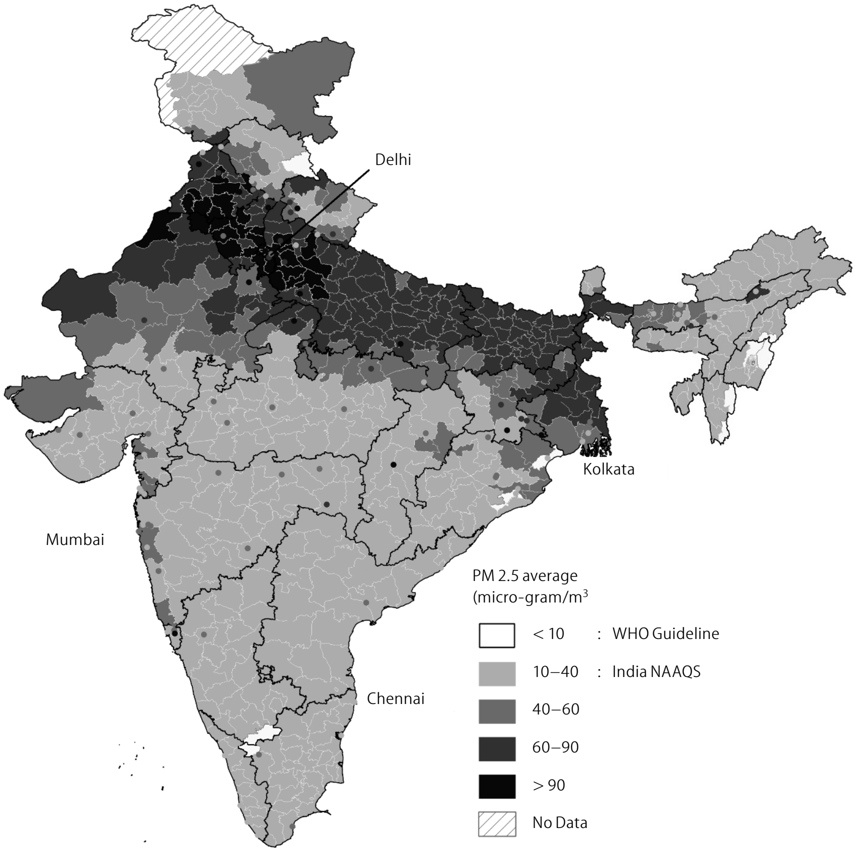
PM Pollution Standards

		India NAAQS 1994[7]	India NAAQS 2009[8]	WHO 2005 (Note 6)
PM_{10}	Annual average	60 μg/m^3	60 μg/m^3	20 μg/m^3
	Daily average	100 μg/m^3	100 μg/m^3	50 μg/m^3
$PM_{2.5}$	Annual average	NA	40 μg/m^3	10 μg/m^3
	Daily average	NA	60 μg/m^3	25 μg/m^3
SPM	Annual average*	140 μg/m^3	Discontinued	NA
	Daily average*	200 μg/m^3	Discontinued	NA

* Standards for residential areas.

allowable concentrations of particulates in ambient air.

Figure 1: Estimates of $PM_{2.5}$ Concentrations across India



* 2001 district boundaries are used in this map.

Our first source of PM data is ground monitoring data obtained from the CPCB's National Air Quality Monitoring Programme. For the recent years 2008–10, data comes directly from CPCB annual reports (CPCB 2009; CPCB 2011; CPCB 2012) which give monitoring station-level annual average concentrations of PM_{10} (respirable PM) and suspended particulate matter (SPM). For earlier years (1987–2007), we use a data set of urban agglomeration-level annual averages of SPM pollution also based on CPCB data and compiled by Greenstone and Hanna (2014). We estimate PM_{10} and SPM annual average concentrations at the urban agglomeration-level as the average of the annual concentrations of all monitoring stations within the urban agglomeration. To estimate the $PM_{2.5}$ annual average concentration in each urban agglomeration in 2010, we assume that the mass ratio $PM_{2.5}/PM_{10}$ equals 0.438, the regional conversion factor recently used by the WHO for India (Note 3).

For areas not covered by the CPCB monitoring network we use satellite measurements of air pollution. Recent advances in satellite-based remote sensing technologies have allowed scientists to construct credible measures of fine particulate concentrations in the air. Dey et al (2012) construct a district-level measure of fine particulate air pollution using data from 2000 to 2010 from the NASA MODIS mission (calibrated against ground monitoring measurements). We use this data set to calculate district-level average $PM_{2.5}$ measures using 2011 district boundaries.

We combine these two data sets, using monitoring data for 2010 where available and satellite estimates otherwise, to create a unified estimate of fine particulate matter ($PM_{2.5}$) concentration levels for every district and urban agglomeration in the country.

2.1 PM Concentrations and Exposure Levels

Figure 1 shows the $PM_{2.5}$ concentrations for every district and urban agglomeration in the country. Average $PM_{2.5}$ concentrations for urban agglomerations, derived from CPCB monitoring data, are represented with small circles. For regions of the country where monitoring data is unavailable, remote sensing data (Dey et al 2012) is used. The figure depicts increasing levels of pollution with darker shades of grey in accordance with the inset guide. Broad areas of the country, particularly in north India, are well out of compliance with the standard. This non-compliance holds in rural as well as urban areas.

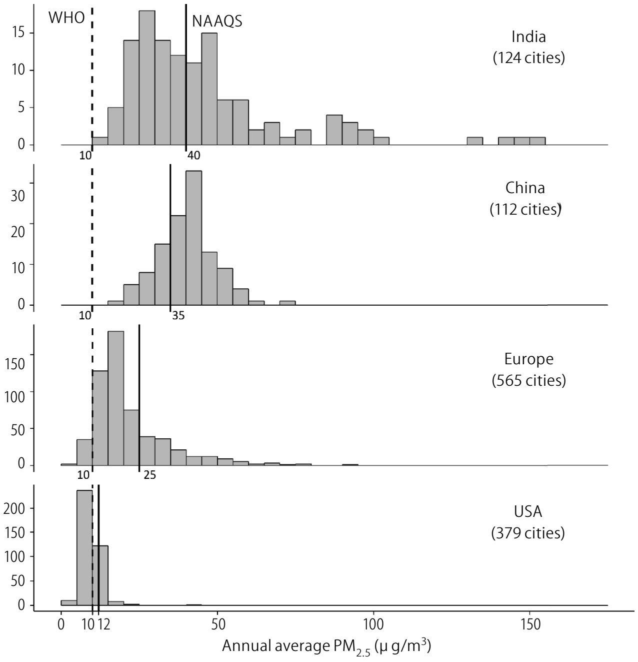
These geographical patterns are consistent with evidence from dispersion models that show how fine particles can travel long distances from where they are originally emitted, imposing health costs on people living far from major sources (Guttikunda and Jawahar 2014). In addition to transport of emissions from urban industrial and transport sources, rural India also directly faces particulate air pollution from local sources, such as biomass combustion (Hanna et al 2012).

Given the widespread and severe nature of India's PM pollution, many Indians are exposed to dangerously high levels of fine particulates ($PM_{2.5}$). Using 2011 Census of India population numbers, we estimate that 660 million people (54.5% of the population) live in regions that do not meet the 40 μg/m^3 NAAQS (Note 8) and 262 million people (21.7% of the population) live in regions with air pollution levels at more than twice this standard. Nearly every Indian (1,204 million people, or 99.5% of the population) lives in an area with $PM_{2.5}$ pollution above WHO's 10 μg/m^3 guideline (Note 6).

Within any single district or city, individual exposure to air pollution will depend on an individual's socio-economic status and ability to avoid high-pollution zones. Thus, traffic policemen will face relatively high pollution levels and richer individuals with access to air purifiers at home will have lower exposures. Equally, individuals who commute by autorickshaw may face greater concentrations than those with access to cars with improved ventilation systems (Apte et al 2011). Put differently, the pollutant concentrations in Figure 1 do not represent the actual exposure to air pollution for any single individual. That said, district-level pollution averages are the relevant parameter for policy action when policymakers cannot control individual exposure to ambient air pollution. For this reason, regulators set policy to affect ambient pollution levels, and the correspondingly relevant variable for policy purposes is average exposure in the population.

In Figure 2 we compare the full distributions of average $\text{PM}_{2.5}$ concentrations across major cities in India, China, Europe and the United States (US), using the WHO Ambient Air Pollution Database. Indian cities, with an average $\text{PM}_{2.5}$ concentration of 46.0 μg/m³, are far more polluted than those in Europe (21.7 μg/m³) or the US (9.6 μg/m³), and polluted even in comparison to China, where cities average 40.4 μg/m³. A number of Indian cities have very high fine particulate levels, above 75 μg/m³. We also compare the ambient air quality standards for annual average $\text{PM}_{2.5}$ concentrations. There is substantial variation in the levels of stringency adopted by countries while setting national air quality standards. At the current prescription of 40 μg/m³ for annual $\text{PM}_{2.5}$, the Indian NAAQS is four times the WHO guideline and is the least stringent of the four regions.

Figure 2: Comparing $\text{PM}_{2.5}$ Annual Average Concentration

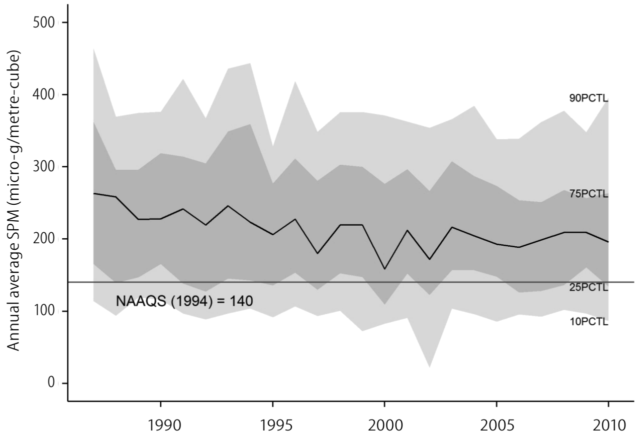


Sources: (1) City-level annual average $\text{PM}_{2.5}$ concentrations for India, China, Europe, and the US from WHO's 2014 "Ambient Air Pollution Database (Note 3).
(2) Ambient air quality standards for annual $\text{PM}_{2.5}$ concentrations from the respective agencies (Notes 6 and 8)[9, 10, 11].

Particulate pollution in India is high, but has it improved over time? In Figure 3 we use historic CPCB data to document trends in the overall average SPM concentration in urban agglomerations covered by the CPCB network ("monitored urban agglomerations"). At no point in the last quarter century have average urban SPM concentrations in India met the 140 μg/m³ SPM standard (Note 7).Despite a very slight downward trend in average pollution over the last 20-plus years, the last five years show no trend towards either improvement or deterioration in air quality.

The shaded bands show the percentile distribution of monitored urban agglomerations based on annual average SPM concentrations. The plot shows that during the 1987–2010 period only about 25% of the monitored urban agglomerations complied with the NAAQ standard of 140 μg/m³. Similarly, about 25% of urban agglomerations experienced pollution levels exceeding 300 μg/m³ or more than twice the NAAQ's prescribed limits.

Figure 3: Average Annual SPM Concentration across Monitored Urban Agglomerations (1987–2010)



3 Impact of Fine Particulates on Life Expectancy

In this section we use the unified measure of fine particulates from Section 2 to calculate the life expectancy gains from reducing $\text{PM}_{2.5}$ pollution to national standards. We begin by reviewing the scientific literature that seeks to relate ambient particulate air pollution over a geographical region to population health outcomes. This relationship differs from an individual exposure-response curve and is an average over a population of individuals — each with unique exposures and responses. However, as mentioned above it is this average response that rightly underlies policy decisions because it is what governments can target.

Several studies from different parts of the world demonstrate a strong positive association between particulate air pollution and mortality rates. But correlation is not causation, and a key research challenge in attributing a causal role to air pollution is isolating the effects of air pollution from other factors that co-vary with air quality. Estimates that use quasi-experimental approaches to identify the causal impact of air pollution are an important way of achieving this (Dominici et al 2014) and we focus our discussion on such studies.

A second consideration in choosing estimates is to measure the effects of sustained exposure to particulate pollution. Arguably, long-run exposure does more harm than contemporaneous impacts from a short-term increase in exposure. In the case of India, several studies of the link between health impacts and ambient pollution (Cropper et al 1997) have primarily focused on the short-term impacts. This limits our ability to use a study from India.

To the best of our knowledge, the only study in a comparable country context that uses quasi-experimental methods and estimates the impact of sustained high air pollution is a recent study gathering data from a number of cities in China (Chen et al 2013).

This paper compares Chinese cities north and south of the River Huai to estimate that long-term exposure to an additional 100 μg/m3 of TSPs reduces life expectancy at birth by roughly three years. We draw on this study to estimate the impacts of India's air pollution on life expectancy. This study measures particulate air pollution in units of TSP, a measure that also includes particles other than $PM_{2.5}$, but that are nevertheless small enough to stay suspended. To apply these TSP estimates to our $PM_{2.5}$ measures of particulate air pollution, we follow Pope and Dockery (2013) and assume the ratio of $PM_{2.5}$/TSPs for the China study is 0.30 (see Box 1).[12]

A useful feature of the estimates from Chen et al (2013) is that they were estimated at high levels of pollution similar to those in India. The SPM levels Chen et al study in China are around 300–600 $\mu g/m^3$, above the average for Indian cities but similar to the more polluted ones such as Delhi. In contrast, most of the other dose-response estimates are derived in the US at $PM_{2.5}$ levels of 10–25 $\mu g/m^3$, which are well below the Indian NAAQS (Correia et al 2013; Laden et al 2006; Pope et al 2002; Pope et al 2009). If the relationship between pollution and mortality depends on the level of pollution, these estimates would not apply well to India. In addition, our choice accounts for the fact that socioe-conomic circumstances and healthcare systems, which affect the relationship between pollution and health impacts, may differ significantly across developed and developing countries (Arceo-Gomez et al 2012; Jayachandran 2009). The main limitation of using the Chen et al (2013) estimate is that it was derived in terms of TSPs, necessitating a conversion to $PM_{2.5}$. An online appendix provides further details on the estimation method, as well as estimates of life expectancy gains based on Chen et al (2013) with several different $PM_{2.5}$/TSPs ratios.

Despite the appeal of estimates based on Chen et al (2013), we also report alternative estimates of the long-term effect of PM on life expectancy. These alternatives are based on research primarily from the US and are shown in Table 1. Laden et al (2006) and Pope et al (2002) are prospective cohort studies and Hoek et al (2013) is a meta-estimate of cohort studies. These papers estimate the increase in mortality risk due to $PM_{2.5}$. Pope and Dockery (2013) use life-table analysis to convert these to life expectancy estimates. The estimates of Pope et al (2009) and Correia et al (2013) are based first on difference analysis of the US county-level changes in $PM_{2.5}$ and life expectancy. Pope and Dockery (2013) review this literature and find estimates of life expectancy reductions between 0.35 and 1.8 years per 10 $\mu g/m^3$ in air pollution; our primary estimate from Chen et al (2013) is roughly equivalent to a figure of one year, i e, in the middle of this spectrum. This suggests our choice of a preferred estimate from among these appropriate estimates is not critical in this context.

Table 1: Summary of Estimates of Marginal Impacts of $PM_{2.5}$ on Life Expectancy

Source	Increase in Life Expectancy per 10 $\mu g/m^3$ Decrease in $PM_{2.5}$ (years)
Chen et al (2013)	1.00
Pope et al (2009)	0.61
Correia et al (2013)	0.35
Pope et al (2002) *	0.73
Laden et al (2006)*	1.80
Hoek et al (2013)*	0.73

* Life expectancy interpretations from Pope and Dockery (2013).

Long-term studies find that a 10 $\mu g/m^3$ increase in $PM_{2.5}$ increases mortality risk about 4%–6% (Pope et al 2002; Hoek et al 2013), while in short-term studies a 10 $\mu g/m^3$ increase in two-day averaged or previous day's $PM_{2.5}$ is associated with an increased daily mortality risk in the range of 0.98%–1.21% (Franklinet al 2007; Zanobetti and Schwartz 2009). Thus using long-term estimates, which can measure the costs of sustained exposure, is important so as not to understate the benefits of reducing pollution.

3.1 Estimating Life Expectancy Loss in India

We combine our district and urban agglomeration-level $PM_{2.5}$ concentration data with our preferred estimates of the mortality response to air pollution to estimate the total life-expectancy loss due to non-compliance with India's air quality standards.

We begin by estimating potential gains in life expectancy if $PM_{2.5}$[13] concentrations in the areas that exceed India's NAAQS were brought down to the standard. For this exercise, we further assume that $PM_{2.5}$ concentrations remain unchanged in places currently below the standard. For each population region (district or urban agglomeration), we estimate potential gains by multiplying different candidate estimates of the marginal effects of $PM_{2.5}$ on life expectancy with the difference between the measured $PM_{2.5}$ concentration levels and the NAAQS of 40 $\mu g/m^3$ annual mean $PM_{2.5}$ — this produces region-specific estimates of the per person gain in life expectancy. For instance, for a district with an annual $PM_{2.5}$ concentration of 50 $\mu g/m^3$, we estimate the gain in life expectancy when its concentration declines exactly to the standard of 40 $\mu g/m^3$ (i e, a decrease of 10 $\mu g/m^3$). We then take the weighted average of these region-specific gains in life expectancy across regions that exceed the $PM_{2.5}$ NAAQS, where the weight is the relevant region's population, which gives the average gain in life expectancy in regions that exceed the standard.

Our preferred estimate based on Chen et al (2013) is that bringing all regions of the country into compliance with the $PM_{2.5}$ NAAQS would increase the life expectancy of the 660 million people living in these areas by 3.2 years on average or a total of about 2.1 billion life years. As Table 2 documents, estimates of potential average life expectancy gains range from 1.1 to 5.7 years, depending on the assumed figure for the marginal

Table 2: Estimates of the Effect of Above-Standard Particulate Pollution on Life Expectancy

Summary Statistics on National Average $PM_{2.5}$ Concentration Levels	
Average $PM_{2.5}$ background concentration for the entire Indian population	50.5 $\mu g/m^3$
Average $PM_{2.5}$ background concentration for the population living in localities that exceed the 40 $\mu g/m^3$ NAAQS	71.7 $\mu g/m^3$
Number of people living in above-standard localities	66,02,41,000
Increase in average life expectancy for affected population if average ambient $PM_{2.5}$ concentrations were reduced to NAAQS (Years)	
Chen et al 2013	3.2
Pope et al 2009	1.9
Correia et al 2013	1.1
Pope et al 2002	2.3
Laden et al 2006	5.7
Hoek et al 2013	2.3

effect of particulates on life expectancy, or from 0.73 to 3.76 billion life years in total. The estimated increases in life expectancy would naturally be larger if these areas achieved the more stringent air quality standards that have been set in other parts of the world.

4 Conclusion and Directions for Policy Response

Is cleaner air incompatible with India's urgent need for economic growth? No. While cleaner air comes with costs, this paper has made plain that there are substantial benefits in terms of longer lives. The people who live longer would be available to contribute to India's economy for more years, beyond the meaningfulness to them and their families of a longer life. Further, it hardly seems far-fetched to assume that cleaner air makes all the more productive due to reduced rates of sickness. In this section, we outline policy reforms that all have the promise of substantial benefits at relatively small costs.

First, improve the accuracy and coverage of pollution monitoring, both in ambient air and at source. As one point of comparison Beijing has 35 monitoring stations,[14] while Kolkata, the Indian city with the most monitoring stations, has only 20. More monitoring stations built in more locations, and in a collaborative manner with independent scientists, will allow for continual improvement in monitoring and the wider use of monitoring data for source apportionment and other scientific purposes. Moreover, regulators should ensure that the monitors are calibrated well and functional and that the data are accessible to the public through traditional and new media outlets. Wide public release can both play an important role as a health advisory system and increase pressure on polluters to comply with regulatory standards (García et al 2007; Tietenberg 1998; Wang et al 2004).

Similarly at source, monitoring of industrial point sources should leverage advances in Continuous Emissions Monitoring Systems (CEMS) technology to produce complete and accurate records of air pollution from every chimney of significant enough size. It is simply not possible to produce a complete record of air pollution sources through intermittent manual samplings taken once or twice in a year. The efforts of the CPCB to adopt standards for PM CEMS monitoring is an important first step in this direction (CPCB 2013). Beyond just setting standards, the CPCB has also recently notified an order to expand CEMS monitoring, for a range of air pollutants, to all industrial plants in the 17 sectors with the highest pollution potential.[15] An expansion of the accuracy and breadth of monitoring will enable smarter policy and greater public awareness of pollution.

Second, restructure environmental law and regulation around civil, rather than criminal, penalties. India's flagship environmental laws, the air and water Acts, are built on an outdated criminal system where draconian penalties such as imprisonment or industry closure are the main recourse available to regulators. These penalties are so severe that they are seldom used, and typically reserved for the very worst polluters (Duflo et al 2013). It would be better to set civil penalties, in accord with the widely-recognised polluter pays principle, so that all industries and other pollution sources have steady, uniformly applied and significant incentives to reduce their pollution output. A pollution tax such as the coal cess, which was levied starting in 2010 at a modest rate of INR 50 per tonne,[16] is a clear example of the application of this principle.

Third, building on the first two, implement market-based environmental regulation, such as emissions trading systems (ETS) (Duflo et al 2010). ETS is based on rigorous monitoring of pollution from all sources. It uses civil and financial penalties rather than criminal sanction to ensure compliance. International experience makes clear that market-based approaches to regulation, like ETS, deliver the least cost way to reduce pollution, making them compatible with the continued economic growth that is vital for India's future.

Today, too many Indians are exposed to dangerous levels of air pollution that are shortening lives and holding back the Indian economy. A variety of effective policy solutions are available that would efficiently reduce this scourge. There is an opportunity to choose longer, healthier, and more productive lives for hundreds of millions of Indians.

NOTES

[1] "Seven Million Premature Deaths Annually Linked to Air Pollution", *World Health Organization,* 25 March 2014, viewed on 1 June 2014, http://www.who.int/mediacentre/news/releases/2014/air-pollution/en/

[2] The standards in question – the NAAQS prescribe a maximum allowable concentration of 60 micrograms/cubic metre for annual average concentrations of the pollutant PM_{10} (particulate matter of less than 10 micrometres in diameter). "National Ambient Air Quality Standards", Central Pollution Control Board, India, 18 November 2009, viewed on 20 January 2014. http://cpcb.nic. in/National_ Ambient_ Air_Quality_Standards.php

[3] "Ambient Air Pollution Database", World Health Organization, May 2014, viewed on 1 June 2014, http://www.who.int/entity/quantifying_ehimpacts/national/countryprofile/ AAP_PM_database_May2014,xls?ua=1

[4] "NCD Mortality, 2008, Chronic Respiratory Diseases, Death Rates Per 100 000 Population, Age Standardised: Female" and "NCD Mortality, 2008: Chronic Respiratory Diseases, Death Rates Per 100, 000 population, Age Standardised: Male", World Health Organization 2011, viewed on 8 February 2014, http://gamapserver.who.int/gho/interactive_charts/ncd/mortality/ chronic_respiratory_diseases/atlas.html

[5] This study measures particulate air pollution in units of TSP, a measure that also includes particles other than $PM_{2.5}$ but that are nevertheless small enough to stay suspended. To apply their TSP estimates to our $PM_{2.5}$ measures of particulate air pollution, we follow Pope and Dockery (2013) and assume the ratio of $PM_{2.5}$/ TSPs for the China study is 0.30 (see Box 1).

[6] "Ambient (Outdoor) Air Quality and Health", World Health Organization. March 2014, viewed on 7 April 2014, http://www.who.int/ mediacentre/factsheets/fs313/en/

[7] "National Ambient Air Quality Standards, 1994" *India Environmental Portal.* December 1994, viewed on 20 January 2014, http://www.indiaenvironmentportal.org.in/content/291574/ national-ambient-air-quality-standards-1994/

[8] "National Ambient Air Quality Standards" Central Pollution Control Board, India, 18 November 2009, viewed on 20 January 2014.

[9] "Ambient Air Quality Standards", Ministry of Environmental Protection of the People's Republic of China, 2012, viewed on 6 June 2014, http://kjs.mep.gov.cn/hjbhbz/ bzwb/dqhjbh/ dqhjzlbz/ 201203/t20120302_224165.htm

[10] "National Ambient Air Quality Standards (NAAQS)", US Environmental Protection Agency, December 2012, viewed on 6 June 2014, http://epa.gov/air/criteria.html

[11] "Air Quality Standards", European Commission: Environment, March 2014, viewed on 6 June 2014, http://ec.europa.eu/environment/ air/quality/standards.htm

[12] This is an approximation and to the extent that the true ratio of $PM_{2.5}$ to TSP in China differs from 0.3, our results on life expectancy will also vary. However, a 10%–20% error in this approximation would not change the thrust of our conclusions. Furthermore, estimates from other studies expressed in $PM_{2.5}$ suggest similar results.

13 Fine particles ($PM_{2.5}$) can get deep into the lungs and are thus the most dangerous. Prospective cohort studies have usually found "the most robust mortality associations with $PM_{2.5}$" (Pope and Dockery 2013: 12861), so this is the appropriate PM measure.

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