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The Economic Implications of Air Pollution: A Case of Two Cities*

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Many cities in urban India, particularly the metros, are major hotspots of air pollution with a PM2.5 concentration level ranging above the permissible limits defined by the World Health Organisation for most of the year. Since the transport sector is a main source of air pollution in urban India, the Government of India adopted BS-VI emission standards in 2016 for all major on-road vehicle categories. The rollout of clean fuel (BS-VI) in India began in the capital city of Delhi, one of the most polluted cities of India. In this context, the primary objective of the article is to analyse the economic cost of air pollution in Delhi/Haryana through a primary survey of occupational groups exposed to ambient air pollution. The secondary objective is to provide suggestive evidences of the implications of the roll-out of cleaner fuel in Delhi while the same was not yet implemented in the neighbouring city of Narnaul in Haryana. We measure the economic cost of air pollution using three approaches, namely, the cost of illness approach, the productivity loss approach and also by undertaking a contingent valuation (CV) exercise. Through a first-of-its-kind CV survey administered in India, the welfare analysis uses the Indian estimates of the value of life years (VOLYs) to arrive at the welfare loss figures. We found that the economic costs in terms of health expenditure and productivity loss were ₹4.08 billion and ₹31.28

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billion, respectively, for New Delhi, which remained higher than Narnaul. Although the cost of pollution decreased during the second phase of the survey towards the end of 2019, we argue that a longer time period analysis is needed to understand the true impact of introduction of the cleaner BS-VI fuel in reducing the impact of air pollution within the city. However, if one considers the value of LYs for Narnaul as a proxy for Haryana, we find that the welfare loss is higher in Haryana than in New Delhi.

Keywords: *Air Pollution, Delhi, Health and Economic Costs, Haryana, BS-VI Fuel*
JEL Codes: *I18, Q51, Q52, Q53, Q58*

1. Introduction

The Health Effects Institute states that air pollution is now the fifth leading risk factor for mortality worldwide and is responsible for more deaths than many known risk factors such as malnutrition, alcohol use, and physical inactivity. In 2017, air pollution alone was associated with 4.9 million deaths and 147 million healthy lives lost. As per the State of Global Air Report, a vast majority of the world's population lives in areas exceeded the World Health Organisation (WHO) guideline for PM2.5; the exposure being the highest in South Asia, followed by western sub-Saharan Africa. In South Asia, Nepal (100 $\mu g/m^3$), India (91 $\mu g/m^3$), Bangladesh (61 $\mu g/m^3$) and Pakistan (58 $\mu g/m^3$) reported the highest levels of pollution (Health Effects Institute, 2019). The second-highest exposure of PM2.5 is found to be in western sub-Saharan Africa. The regions of North Africa, Middle East and East Asia share almost similar PM2.5 distribution levels. Countries with the lowest national exposure to PM2.5 are Maldives, the United States, Norway, Estonia, Iceland, Canada, Sweden, New Zealand, Brunei, and Finland.

Chronic exposure to ambient air pollution poses serious health hazards and is a major risk factor for different types of illnesses, such as chronic obstructive pulmonary disease (COPD), ischemic heart disease, stroke and lung cancer for adults, and acute lower respiratory infection for children (Burnett et al., 2014; Jain et al., 2017; Pope et al., 2004). Epidemiological studies based on a vast array of literature have established robust causal associations between long-term and continuous exposure to pollution to premature mortality from the above health endpoints, thereby substantially reducing life expectancy (LE) (Anenberg et al., 2010; Lepeule et al., 2012). The Public Health and Air Pollution in Asia (PAPA) study, in their multi-city project, analysed the effects of short-term exposure to air pollution on daily mortality in Bangkok, Thailand and in three cities of China, viz., Hong Kong, Shanghai and Wuhan. The study showed that residents of the Asian cities are likely to have higher exposures to air pollution. The association between ambient pollutants and negative health outcomes such as cardiovascular and respiratory mortality is higher in Asian cities than in cities of western industrial nations (Wong et al., 2008). Son and Bell (2013) used a 10-year time series data of Seoul to conclude that a 10 μg/m³ increase in a 24-hour period, including daytime, morning and night-time, and 1-hour exposure to maximum PM10 levels was associated with a 0.15, 0.14, 0.10, 0.12, and 0.10 percentage increase in total mortality, respectively. Another cohort study, in which individuals exposed to air pollution concentrations were followed up for years, also found mortality to be strongly associated with spatial differences in the long-term average concentration of PM2.5. The results remained significant even after controlling for smoking and individual risk factors (Krewski et al., 2009).

The early mortality and morbidity from air pollution results in a significant economic cost for the society as a whole. A region-wise analysis by the World Bank shows that the economic cost of air pollution in absolute figures has increased significantly and that the damages resulting exclusively from ambient PM2.5 rose by 63 per cent between 1990 and 2013, amounting to $3.55 trillion. The total cumulative loss in South Asia due to air pollution turned out to be $604 billion in 2013, which represents a 347-percentage increase over 1990 (World Bank, 2016). In another report by the WHO Regional Office for Europe and the Organization for Economic Co-operation and Development (World Health Organisation, 2015), the economic cost resulting from 600,000 premature deaths and associated diseases caused by air pollution was estimated to be $1.6 trillion, which was equivalent to one-tenth of the GDP of the entire European Union in 2013. The economic value obtained corresponds to the amount societies are 'willing to pay in order to avoid the deaths and diseases related to air pollution with necessary interventions'. Estimating country-specific economic costs is important to ensure that policymakers take note of this silent killer and devise policies that can curb pollution and the resultant economic costs.

2. Air Pollution in Indian Cities

In the context of India, as per the limits set by the National Ambient Air Quality Standards, 76.8 per cent of the entire population lives in areas beyond the permissible pollution limits. The Global Burden of Disease (GDB) study reported that the mean exposure to ambient particulate matter was 89.9 μg/m³, making air pollution the third leading risk factor for mortality for the country. Among the Indian States, the annual population-weighted mean PM2.5 is found to be the highest in Delhi, followed by Uttar Pradesh, Bihar and Haryana, all of which have a mean PM2.5 value greater than 125 μg/m³.

The India State-Level Disease Burden Initiative studies show that malnutrition and air pollution are the two topmost contributors to India's disease burden, with mortality from the ambient particulate matter contributing the most (Murray et al., 2020). The Institute of Health Metrics and Evaluation estimated that in 2005, India's death toll due to air pollution-related premature deaths was 620,622, which increased by 12 percentage points to 692,425 in 2010. The figures rose to 1.24 million (1.09–1·39) in 2017, which was almost twice of the corresponding values recorded in 2010. Of these, ambient particulate matter pollution attributed to 55 per cent of the deaths, while the rest were due to indoor air pollution (Balakrishnan et al., 2019). If we group the Indian states by Socio-Demographic Index (SDI) levels, we would see that the air pollution levels are poorest in the low SDI states (PM2.5 $\mu g/m^3$ is 125.3), which also share a disproportionately high mortality and disease burden, followed by the middle SDI states (58.7 $\mu g/m^3$) and the high SDI states (58.7 $\mu g/m^3$). As per 2020 pollution levels, citizens in the regions that fall in the north of the Tropic of Cancer (which cuts India almost by half), lose an average of 6.6 years of LE, which is 3.3 years when compared with the LE for citizens living to the south of the Tropic of Cancer line (EPIC India, 2023).

Etchie et al. (2017) conducted a burden analysis of air pollution in the Indian city of Nagpur. They found that in 2013, ambient air pollution contributed to 300 deaths, 91,000 Disability-adjusted Life Years (DALYs) and \$2.2 billion loss for the city. They concluded that interventions to reduce pollution can avert the health loss and translate into an impressively large health and economic gain. Ghude et al. (2016) used a regional chemistry model to find that PM2.5 exposure led to about 570,000 premature mortalities in 2011; 42 per cent of the estimated mortalities took place in the Indo-Gangetic region. This translated into a total economic cost due to premature mortality to about \$640 billion (350–800) in 2011. According to the state-wise estimates of the economic cost, Uttar Pradesh, at \$98 billion, suffered the highest economic loss, followed by Maharashtra (\$62 billion), West Bengal (\$57 billion) and Bihar (\$53 billion). They also calculated an expected loss in life year (LE) by about 0.061 ± 0.02 years for an increase of 1 $\mu g/m^3$ in PM2.5 concentrations. This corresponds to a loss of LE of 3.4 years for all of India and 6.2 years for Delhi. An estimate from the OECD suggests that ambient air pollution alone may cost India more than 0.5 trillion dollars per year (OECD, 2014). The above studies signify the harmful effects of air pollution and project the magnitude of economic loss due to the same. They suggest the need to implement strategies aiming to curb the level of ambient air pollution.

Towards this, special efforts have been made by the Ministry of Road Transport and Highways (MoRTH), Government of India to reduce the ground level air pollution. In 2016, the Government of India issued a notification to implement BS-VI emission standards, for all major on-road vehicle categories

('Notification No. G.S.R. 889(E), dated 16 September 2016 regarding mass emission standards for BS-VI' n.d.). BS-VI aimed to bring more stringent and robust emission standards that are in alignment with the European Union regulation. Targeting air pollution originating from the transport sector holds critical importance, given that 40 per cent of the air pollution emanates from this source. The role of such a policy in limiting vehicular pollution in the longer term is discussed in Pohit et al. (2021).

The transition to the cleaner BS-VI fuel took place in a phased manner. It commenced in April 2018 in Delhi and was thereafter implemented countrywide starting from April 2020. This would have provided a natural experiment to test the effectiveness of clean fuel, with Delhi being in the treatment group and the National Capital Region (NCR) surrounding Delhi in the control group. However, one should understand the geography of Delhi, and the fact that it is landlocked from the surrounding states. Delhi gets a lot of daily traffic from NCR, which contributes significantly to the vehicular pollution of Delhi. Hence, it is difficult to estimate the true effect of BS-VI cleaner fuel on Delhi pollution unless the same is also simultaneously implemented in NCR.

With this limitation, in this article, we attempt to primarily evaluate the economic cost arising out of vehicular air pollution focusing on the people of New Delhi who are exposed to air pollution. We also attempt to provide some suggestive comparisons of the differences in economic costs arising out of air pollution between Delhi and Narnaul, a city in one of the NCR states, Haryana. This is done in the context of introduction of cleaner fuel (BS-VI) in Delhi while in Narnaul, BS-IV fuel was still in circulation. However, as mentioned above, one should view the case-control comparisons in the light of the two limitations; first, the geographical positioning of Delhi, and second, the insufficient sampling of respondents in Narnaul. An important and innovative contribution of this study is the welfare analysis through the estimation of the VOLY lost. In a first-of-its-kind contingent valuation (CV) survey administered in India, the welfare analysis uses the Indian estimates of VOLY to arrive at the economic loss figures. In this respect, this study differs from all other studies that estimate mortality loss for India arising from air pollution using samples originating from the developed countries.

The plan of the rest of the article is as follows. Section 3 briefly discusses the various approaches to measure the economic costs of air pollution. Here, we describe the cost of illness (COI) approach, the productivity loss approach and the conceptual reasoning for undertaking a welfare evaluation. In Section 4, we talk about the survey framework adopted to collate the data, along with the basic features of our questionnaire. Section 5 discusses our results separately for all the measures of economic costs, and finally in Section 6, we summarise our study along with its limitations.

3. Economic Costs of Air Pollution: Methods and Rationale

At the outset, it may be pointed out that there is no standard method of estimating the loss of a valued item like health in the economic literature. The mortality and morbidity arising from air pollution leading to socio-economic burden can be a summation of both financial and non-financial costs. Hunt and Ferguson (2010) proposed a methodology whereby the economic cost can be measured in terms of *resource cost*, which is a summation of all the different types of direct medical and non-medical costs associated with treatment for any adverse impact of air pollution. The incidence of any disease also has an *opportunity cost*, which is an indirect cost related to the loss of productivity and/or leisure time due to the health impact. Finally, there are *disutility costs*, which refer to the intangible costs caused by pain, suffering, discomfort and anxiety linked to the illness. The epidemiological literature estimates mortality in terms of the number of premature deaths, the years of life lost (YLLs) and in terms of quality-adjusted life years lost (QALYs). Economists later proposed a method determining the measure of 'economic cost' of morbidity through the 'value of a life year lost' (VOLY) (also known as 'value of a statistical life year' or VSLY) (OECD, 2014). Stated preference approaches like CV are the most appropriate methods used to arrive at the VOLYs for a country. Welfare analysis is done using the willingness to pay (WTP) approach, which monetises the individuals' perceived risk from air pollution. The approach entails asking individuals to indirectly value a government policy for achieving cleaner air through the valuation of premature mortality. As Viscusi (1993) and Cropper (2000) put it, individuals, through their measure of valuation, estimate the threat that air pollution imposes both on society and also on themselves. Hence, valuation captures the trade-offs that individuals are willing to make to reduce their chances of dying. The amount neither represents any single person's life or death nor a normative analysis of the societal valuation to the death. But it is only a perceived valuation of the mortality risks associated with pollution.

In this article, we have employed the three dominant approaches proposed in the literature to calculate the economic costs that air pollution imposes on a society. These are outlined below.

The COI approach measures the direct, indirect and 'intangible costs' associated with adverse effects of air pollution. Health care costs include the medical care expenditures for diagnosis and treatment, whereas the non-health costs include any expenses incurred on account of transportation, household expenditures and other informal care of any kind (Jefferson et al., 2000; Jo, 2014).

The number of workers missing out on the days at work due to health-related disabilities and the associated loss of income provides a societal perspective of the amount of 'productivity loss' due to disease. This approach assumes that individuals have the potential to produce a stream of outputs over their working lives, which may be reduced due to illness. The work time lost is then valued at the market wage rate reflecting the value to the society (Pearce, 2016).

Hunt (2011) noted that COI estimates, though a useful measure of the financial burden of disease, are insufficient if one has to arrive at a full cost–benefit analysis of public policies aimed at reducing morbidity or mortality. The welfare loss approach, through the WTP, is a more appropriate measure of the change in welfare in the cost–benefit analysis. Welfare analysis reflects not only the financial effect but also the value that people place on the effect on quality of life and longevity. The established literature on the country-specific value of statistical life lost due to air pollution is available for the developed countries. The numbers for developing countries, including India, have been arrived at on the basis of these numbers and after adjusting for differences in the per capita GDP at Purchasing Power Parity (PPP) with income elasticity estimates (OECD, 2014). The total economic cost of deaths from ambient air pollution was estimated at $232.736 million in 2005, which registered a 60 per cent increase in the value of statistical life in 2010 at $416,704 million. These estimates may be over-estimations since the samples used to derive the Indian numbers have been taken from the developed countries. The respondents in the developed countries can be structurally different from their counterparts among the Indian population with regard to their exposure to pollution and the knowledge of pollution implications. Hence, estimating the cost using data collected from the Indian population would be a preferable measure.

An important and innovative contribution of this study is the welfare analysis undertaken through the estimation of VOLY. In a first-of-its-kind CV survey administered in India, the welfare analysis uses the Indian estimates to arrive at the economic loss figures. The theoretical understanding behind the calculation of VOLY is explained below.

The expected utility function (EU) of an individual relates the utility that they derive from the consumption of any good given by $U(y)$ and the disutility derived from the risk of mortality from air pollution (r). The expected utility function is:

$$EU(y, r) = (1 - r)\ U(y).$$

In the event of introduction of a government policy which proposes a reduction in the risk of pollution, and therefore, indirectly a reduction in the risk of dying, under the CV exercise, individuals are asked whether they want to trade-off some amount of their present consumption for a reduction in the level of risk from r to r` such that the EU remains the same.

$$EU(y, r) = (1 - r)\ U(y) = EU(y - WTP, r`);\ r` < r$$

The non-parametric WTP group-wise numbers of the sample population are used to estimate the VOLY (Desaigues et al., 2007). The calculation uses the gender-wise LE figures and the age of the individuals to arrive at the values. The formula used is as follows:

$$VOLY_k = (WTP_{1,k} \times 12) \times (LE_i - age)$$

where $VOLY_k$ represents the value of life years for different groups, $WTP_{1,k}$ records the willingness to pay for one year of additional LE, $(LE_i - age)$ is the remaining LE of each individual where the LE_i values are gender-specific. Multiplying by 12 gives the annual VOLY figures. Before the respondents are asked the question regarding their WTP, they are made aware of the good that they are valuing through a script. This script is called *Cheap Talk* in the CV literature, which describes the good to be valued, and the benefits that the wilful contribution will bring to the individual and to the society. It also explains the opportunity cost associated with making such payments.

4. Survey Framework and Questionnaire Design

The survey was conducted in two phases at six locations in Delhi, and at one location in Narnaul, Haryana. At the time of the survey, Narnaul had seen the implementation of BS-IV fuel whereas Delhi has already been brought under the BS-VI regime. Narnaul is located about 200 kilometers from the centre of New Delhi. The first phase of the survey took place in the month of March 2019, whereas Phase II was conducted in the months of November–December 2019. This was done to account for seasonality in air pollution implications.

The sample sites were purposively chosen to represent populations belonging to two-fuel regimes and also to capture groups that are more exposed to pollution, such as bus drivers, conductors, street vendors, construction workers and office staff of the bus depots. The samples were randomly chosen from each of these study sites.

The Delhi Transport Corporation (DTC) is the main public transport operator of Delhi. The bus drivers and DTC office staff have been sampled from DTC bus depots, especially the bus depots of Harinagar, Hasanpur and Shadipur, whereas for selecting the street vendors, the focus was on areas such as Anand Vihar and Dabri Mor in New Delhi, which are busy streets across Delhi with clusters of street vendors. These groups were simultaneously surveyed at the Narnaul bus depot too. A total sample of 1,400 individuals was randomly chosen from each of the study sites, as shown in Table 1. On an average, the number of bus movements per day at a bus depot in Delhi ranges from 724 at the Anand Vihar depot to 1,183 at the Shadipur bus depot. The vehicular movement inclusive of all types of vehicles is as high as 71,000 at the Shadipur depot, and 60,500 and 64,350 at the Anand Vihar and Harinagar depots, respectively. The corresponding figure is 21,500 at the Narnaul bus depot.

A face-to-face computer-assisted personal interview was conducted on the randomly selected samples using a structured questionnaire. The survey includes questions on the perception of air pollution, the types of diseases that individuals face on account of air pollution, and the direct and indirect expenditures incurred as a result of the adverse implications of pollution. We also asked questions on the number of missed working days due to air pollution-related sickness and finally if the respondents were willing to pay anything for ushering in an improvement in the air quality.

As noted earlier, the results only provide suggestive evidences of the changes in the economic cost arising from a change in the fuel regime. Economic comparisons between two states would be meaningful if the states concerned are similar in their socio-economic and demographic profiles. In our case, comparing New Delhi, which is a high-density metropolitan city, with Narnaul,

Table 1 Stylised Facts on the Sample

Location	*Phase I*	*Phase II*	*Tracked Respondents (%)*	*Total Sample*
Delhi (BS-VI fuel)	623	625	45.42	1248
Hasanpur	109	129	53.2	238
Shadipur	104	107	48.07	211
Harinagar	122	141	53.27	263
Construction site	168	137	23.2	305
Anand Vihar	56	45	48.21	101
Dabri	64	66	68.75	130
Narnaul (BS-IV fuel)	57	91	29.82	148

Source: Compiled by the authors.

a municipal council in the Mahendragarh district of Haryana, has its own disadvantages. Narnaul comprises only 0.89 per cent of the total population of Delhi in 2011 and is structurally different in terms of the car density and penetration. Also, both the phases of the survey were conducted before BS-VI cars were fully available in the market. Hence, cleaner fuel was mostly being used in BS-IV cars during our study period, which probably leads to an under-estimation in the economic benefits of the use of clean fuel. Therefore, long-term research is needed to ensure a comprehensive estimation of the economic benefits of use of cleaner fuel. These caveats need to be noted while we discuss the results below.

5. Analysis of the Results

The principal results from our study are discussed in the following three sub-sections.

5.1 Findings from the Cost of Illness Approach

In this sub-section, we present the direct medical expenditures borne by the respondents on account of any air-pollution borne disease. Each individual was asked if they had suffered from any diseases on account of ambient air pollution in the previous three months. Depending on their responses, they were further asked about the concomitant actions they would have taken towards the treatment of those diseases. The total health expenditure reported in Table 2 is a summation of the medical expenditure cost and transportation cost incurred by the respondents for availing of the treatment for their diseases. It is evident from Table 2 that the mean health expenditures for Delhi were higher than those for Narnaul during both the phases. Also, as one would expect, the expenditure was higher during Phase 1 than during Phase 2, as Phase 2 captured the health

Table 2 Mean Health Estimates Arising out of Air Pollution

Health Expense (Sample Estimates)	*Health Expenses (₹)*	
	New Delhi	*Narnaul*
Phase I	1,403.03	1,188.08
Phase II	876.97	122.68
Appended	1,210.43	524.03
P Value	.0027	.0074

Source: Computed by the authors.

Table 3 Total Weighted Health Expense of New Delhi and Haryana Resulting from Respiratory Illnesses (₹Billion)

Total Health Expenses	*Delhi*			*Haryana*		
	Phase I	*Phase II*	*Appended*	*Phase I*	*Phase II*	*Appended*
Sensitivity 1	1.18	1.001	1.02	1.66	0.171	0.73
Sensitivity 2	0.62	0.531	0.54	0.95	0.098	0.42

Source: Computed by the authors.

expenditures incurred during the winter months when the air pollution levels are relatively higher than during the other months.

The average expenditures reported in Table 2 are the sample estimates obtained from the survey, which is then weighted to project an approximate amount of health expenditure that is likely to be incurred in New Delhi and Haryana at a population level. We relied on the literature review and extrapolated prevalence rates from the published literature (see Salvi et al., 2018). The GBD study came up with modelled estimates of the number of chronic respiratory diseases likely to be occurring in the Indian States. Using these GBD estimates, especially for COPD and asthma, and our sample estimates of the average amount of health care expenditures, we provide a crude projection of the total direct cost likely to be associated with air pollution for the states of New Delhi and Haryana (Table 3). It must, however, be acknowledged that these are crude figures, especially given the limited number of samples from Haryana.[1] We also ran a sensitivity analysis to take into account two sets of reported figures for different ailments concerning pollution for Delhi and Haryana, respectively. The figures for the occurrence of COPD and asthma in Delhi are 843,000 and 447,000, respectively, while the corresponding figures for Haryana are 1,401,000 and 804,000, respectively. Using these figures, we found that the health expenses on account of air pollution can be as high as ₹1.02 billion and 0.73 billion for Delhi and Haryana, respectively.

5.2 Results from the Productivity Loss Approach

Typically, the practice is to examine the direct medical expenditures to come up with out-of-pocket spending as an indicator of the economic burden; however, including the workforce implications of the economic burden provides a broader

[1] We calculated income elasticity, which is estimated to give the readers an idea of how individuals at different levels of income respond to health expenditures. We found that health expenditure is income-inelastic ($e < 1$). This holds true for all the phases and also for the appended data set.

view of economic impacts. Productivity loss does not necessarily represent a loss of income to the individuals but is a loss to the economy. The incidence of workers missing out on the days at work due to health-related disabilities and the associated loss of income imparts a societal perspective to the burden of disease. Productivity loss can be incorporated into economic evaluations along with the premature mortality costs for informed decision-making.

Health-related disutility impacts the productivity of individuals due to the number of missed workdays and foregone labour output. In our survey, we specifically ask if the respondents have missed out on the days at work due to any air pollution-related diseases. In both the phases, we found that a majority of the respondents did not miss any workday due to reasons related to pollution. However, 10.16 per cent (9.18 percentage) of the respondents in Delhi and 12.73 per cent (7.78 percentage) of the respondents in Narnaul in the respective phases said that they had missed 1–3 days of work. In Delhi, we also see at least 11 percentage and 9 percentage of the respondents having missed work for more than 5 days (Table 4). The distribution looks similar in the case of the Narnaul population, wherein about 79 per cent of the respondents had not taken any leave of absence and 4 per cent had missed 6–10 days of work due to illnesses related to air pollution.

Using the human capital approach methodology, we have estimated the average productivity loss for Delhi and Narnaul separately for Phase I and Phase II. The mean productivity loss calculation used the midpoint of the average number of days missed at the workplace and the average income reported by the respondents of different occupation groups.

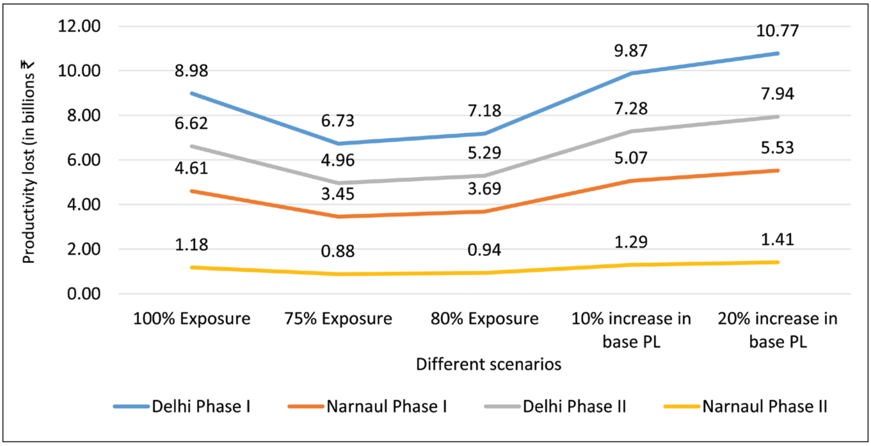
Different scenarios have been simulated to indicate a range of productivity loss, as given in Figure 1. Using all the simulated conditions, it is seen that the mean productivity loss ranged from ₹8.98 billion to ₹10.73 billion for Delhi

Table 4 Number of Missed Workdays due to Air Pollution-borne Diseases (Percentage of the Sample)

	Phase I (%)		*Phase II (%)*	
Days Missed	*Delhi*	*Narnaul*	*Delhi*	*Narnaul*
0 Days	77.90	78.0	82.13	92.22
1–3 Days	10.16	12.73	9.18	7.78
4–5 Days	4.03	5.45	4.35	0
6–10 Days	3.87	3.18	2.42	0
11–15 Days	1.77	0	0.97	0
More than 15 Days	2.26	0	0.97	0

Source: Computed by the authors.

Figure 1 Simulated Productivity Lost (₹ Billion)



Source: Computed by the authors.

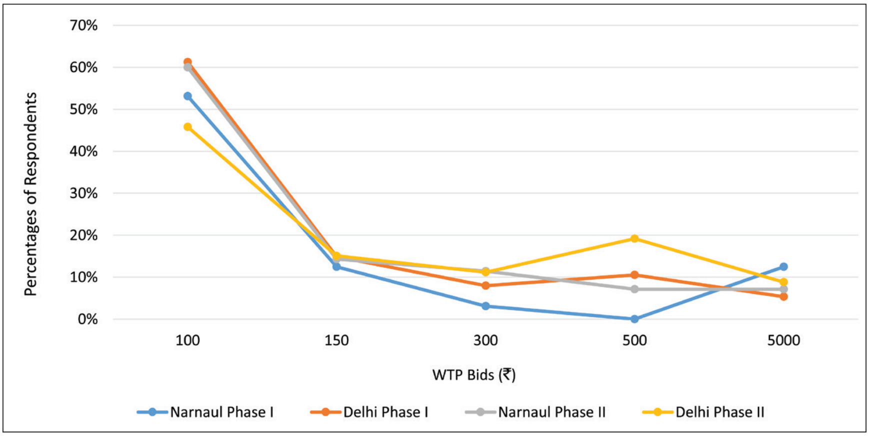
Note: The figures in the graph are based on alternative assumptions as articulated below. Members of the entire labour force in both Delhi and Haryana are exposed to pollution and will, therefore, suffer from similar effects (Government of Haryana, 2019). The alternative assumptions are with 75 per cent of exposed labour force and 80 per cent exposure. Similar scenarios are also run with a 10-percentage point increase in the mean productivity loss or a 20 per cent increase in the mean productivity loss. The productivity figure has been adjusted using the per capita income of Delhi and in terms of the labour force and unemployment rates.

in Phase I, which decreased to ₹6.62 billion to ₹7.94 billion in the subsequent phase. The trend is also similar for Narnaul, where the productivity loss that ranged between ₹4.61 and ₹5.53 billion in the first phase declined to ₹1.18–₹1.14 billion in the following phase. If we disaggregate the productivity loss by the occupational groups (not shown here), we find that the losses are higher for all the groups in Phase 1 in comparison to Phase II. For instance, in the case of ‘bus drivers and conductors’, the average loss decreased from ₹2,540 to ₹1,924, whereas the corresponding figures were ₹2,111 versus ₹1,845 for office staff. As in the case of the COI approach, we can infer that: (a) for Delhi, irrespective of the seasons, the loss to society is relatively higher in all the simulated conditions and (b) the loss of productivity is higher in Phase 1 than in Phase II in both the places, which captures the effects of seasonality.

5.3 Results from Welfare Analysis

Respondents were first presented with a CV script and were asked how much they were willing to pay for having one more year of good quality of life in a

Figure 2 Percentages of Respondents by Their WTP



Source: Computed by the authors.

double-bounded CV exercise. In both the phases, more than 80 per cent of the respondents agreed to pay for a government policy that would ensure better air quality. Among those who were not willing to pay, a general distrust about the effectiveness of government policy is observed. As expected, in Figure 2, we observed a downward sloping demand curve of clean air. At the lower bids, the proportion of respondents willing to pay for a higher amount is found to be higher than 60 per cent, which subsequently and monotonically decreased as the amounts sought from the respondents increased.

We used the WTP figures and calculated the VOLY for all the groups individually for both the Delhi and Narnaul samples. Table 5 provides the important finding that the social returns or perceived health benefits of improved air quality are valued higher in Phase II in comparison to Phase I in Delhi. This can be due to the increase in awareness regarding air pollution in the peak pollution seasons.

The average VOLY figures are then weighted using the premature mortality numbers from the GBD study by Balakrishnan et al. (2019) to yield a range of the economic cost of deaths from ambient air pollution in Delhi and Haryana, respectively. The GBD study records premature mortality due to ambient air pollution for all the states and union territories of India, which was 11,732 for Delhi and 19,788 for Haryana in 2017. The welfare loss is calculated as:

$$Welfare\ loss_{states} = n \times Average\ VOLY_{states}$$

The estimates show that the approximate economic costs or the amounts lost by Delhi and Haryana in 2017, are ₹0.91 billion and ₹1.54 billion, respectively.[2]

6. Conclusion

In this article, we aimed to study the economic impacts of air pollution of Delhi and analysed it in the light of implementation of a new cleaner fuel policy being implemented by the Government of India. We took Narnaul, a city in Haryana, as a reference group when the cleaner fuel (BS-VI) was not yet operational during the periods of the survey. A face-to-face survey was conducted in two phases among different groups of respondents who were the most exposed to pollution, such as bus drivers, conductors, street vendors, construction workers and office staff. The survey took place in both the Delhi and Narnaul regions. The economic cost imposed by air pollution on the society was evaluated holistically to include the direct cost of treatment, indirect cost of loss of productivity and through welfare analysis. We found that the economic cost of air pollution for Delhi is higher, that is, about ₹4.08 billion and ₹31.28 billion, when measured in terms of health expenditure and productivity loss, respectively, as compared to the corresponding costs of ₹2.92 and ₹10.32 billion, respectively, incurred in Narnaul. In the case of Delhi, the direct and indirect health expenditure accounts for 0.4 per cent of the state GDP.[3] As also mentioned above, a longer time period is needed for analysis to understand the true impact of the introduction of BS-VI fuel in reducing the impact of air pollution within the city. However, one can find suggestive evidences of the implications of air pollution while comparing the Phase I and Phase II costs of pollution among the respondents of Delhi. We have contributed to the literature by incorporating estimates from the Indian sample, whereas earlier that analysis was derived from the developed country samples.

Our estimates are conservative as compared to the magnitude of pollution reported by other studies such as Dalberg (2021), which reports that the problem of air pollution had cost Delhi about $5.6 billion, which amounts to 6 per cent of the state's GDP in 2019. This figure is disproportionately higher than the ~3 per cent cost of air pollution on India's overall GDP in relative terms. Another report published by the System of Air Quality and Weather Forecasting and

[2] Data for the premature mortality figures have been extracted from the Institute for Health Metrics and Evaluation (2013), The Global Burden of Disease (GBD) report. The premature mortality rate in 2017 was 11,732 for Delhi and 19,788 for Haryana.

[3] With Narnaul being a city in Haryana, it would not be justified to provide such an estimate.

Table 5 Value of Life Years (₹)

	Phase I		*Phase II*		*Appended*	
Occupation	*Delhi*	*Narnaul*	*Delhi*	*Narnaul*	*Delhi*	*Narnaul*
Bus driver and conductor	76,978	119,280	101,444	80,258	89,306	92,065
Office staff	60,428	96,840	79,349	77,310	69,992	84,650
Street vendor	89,494	121,680	109,727	84,471	100,604	95,877
Construction worker	88,568	–	127,103	–	106,089	–
Construction control	86,907	–	114,010	–	100,604	–

Source: Computed by the authors.

Research (SAFAR) estimated that the annual average total cost of all illnesses caused by air pollution in Delhi is around ₹7,694 crore, of which the highest costs are those incurred on the treatment for allergic rhinitis, at ₹1,449 crore, followed by treatment for asthma, at ₹1,001 crore (*The Economic Times*, 2021).

Although the estimates of different studies may vary due to the differences in samples and study sites, the overall consensus that air pollution imposes a significant economic cost on the society is evident from all the studies. However, one should acknowledge and interpret the results in the light of certain limitations. The cost of health care or the health expenditures are directly proportional to the uptake of health care services and can only serve as an indicator for the utilisation patterns. These values should thus be judged with reference to each group's affordability of the health utilisation plans. The differences in health expenditures that are reflected in the two phases can also represent the effects of seasonality. Hence, it is important to examine the appended figures to obtain an overall cost of air pollution for the states. The sample size and the choice of the reference groups in Narnaul are too limited for arriving at any certain conclusion on the effect of BS-VI fuel. As is the case with Delhi, where a longer time period is needed to understand the true effect of BS-VI, similarly, a varied and heterogeneous sample is needed to understand the effect of BS-VI among the differentially exposed population.

Different anti-pollution measures have been implemented in Delhi in the recent past, including the Graded Response Action Plan, National Clean Air Programme and the Odd-Even Scheme, among others, to curb the effects of air pollution. However, given the geography of Delhi, subsequent policies to address the ambient air pollution from the neighboring states are also needed. The initiative to leapfrog to the use of the cleaner BS-VI fuel directly from BS-IV signifies a holistic solution for mitigating air pollution. A longer time series study is needed to assess the full effects of such a policy in reducing the economic costs of air pollution.

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References

Anenberg, S. C., Horowitz, L. W., Tong, D. Q., & West, J. J. (2010). An estimate of the global burden of anthropogenic ozone and fine particulate matter on premature human mortality using atmospheric modeling. *Environmental Health Perspectives*, *118*(9), 1189–1195.

Balakrishnan, K., Dey, S., Gupta, T., Dhaliwal, R. S., Brauer, M., Cohen, A. J., Stanaway, J. D., Beig, G., Joshi, T. K., Aggarwal, A. N., Sabde, Y., Sadhu, H., Frostad, J., Causey, K., Godwin, W., Shukla, D. K., Kumar, G. A., Varghese, C. M., Muraleedharan, P., …, Dandona, L; India State-Level Disease Burden Initiative Air Pollution Collaborators. (2019). The impact of air pollution on deaths, disease burden, and life expectancy across the states of India: The global burden of disease study 2017. *The Lancet Planetary Health*, *3*(1), e26–e39.

Burnett, R. T., Pope, C. A., III, Ezzati, M., Olives, C., Lim, S. S., Mehta, S., Shin, H. H., Singh, G., Hubbell, B., Brauer, M., Anderson, H. R., Smith, K. R., Balmes, J. R., Bruce, N. G., Kan, H., Laden, F., Prüss-Ustün, A., Turner, M. C., Gapstur, S. M., Diver, W. R., & Cohen, A. (2014). An integrated risk function for estimating the global burden of disease attributable to ambient fine particulate matter exposure. *Environmental Health Perspectives*, *122*(4), 397–403.

Cropper, M. L. (2000). Has economic research answered the needs of environmental policy? *Journal of Environmental Economics and Management*, *39*(3), 328–350.

Dalberg. (2021). Air pollution and its impact on business: The silent pandemic. *Statista*. https://s40026.pcdn.co/wp-content/uploads/01042021_Business-Cost-of-Air-Pollution_Long-Form-Report.pdf

Desaigues, B., Ami, D., Hutchison, M., Rabl, A., Chilton, S., Metcalf, H., Hunt, A., Ortiz, R. A., Navrud, S., Kaderják, P., Szántó, R., Nielsen, J. S., Jeanrenaud, C., Pellegrini, S., Kohlová, M. B., Ščasný, M., Máca, V., Urban, J., Stoeckel, M., Bartczak, A., Markiewicz, O., Riera, P., & Farreras, V. (2007). Final report on the monetary valuation of mortality and morbidity risks from air pollution. Deliverable D67.

EPIC India. (2023, January 30). Top 5 pollution charts from India. *EPIC India News*. https://epic.uchicago.in/clean-air-countdown/

Etchie, T. O., Sivanesan, S., Adewuyi, G. O., Krishnamurthi, K., Rao, P. S., Etchie, A. T., Pillarisetti, A., Arora, N. K., & Smith, K. R. (2017). The health burden and economic costs averted by ambient PM 2.5 pollution reductions in Nagpur, India. *Environment International*, *102*, 145–156.

Farreras, V. (2007). Final report on the monetary valuation of mortality and morbidity risks from air pollution. *Deliverable D67*. https://doi.org/10.13140/2.1.2737.6327

Ghude, S. D., Chate, D. M., Jena, C., Beig, G., Kumar, R., Barth, M. C., Pfister, G. G., Fadnavis, S., & Pithani, P. (2016). Premature mortality in India due to PM 2.5 and ozone exposure. *Geophysical Research Letters*, *43*(9), 4650–4658.

Government of Haryana. (2019). Statistical abstracts of Haryana 2017–18. http://esaharyana.gov.in/Portals/0/Compilation/Abstract%202017-18%20(English).pdf

Health Effects Institute. (2019). State of Global Air 2019. A Special Report on 'Global exposure to air pollution and its disease burden'. Health Effects Institute.

Hunt, A. (2011). Policy interventions to address health impacts associated with air pollution, unsafe water supply and sanitation, and hazardous chemicals [*OECD Environment Working Papers No. 35*]. OECD Publishing. http://dx.doi.org/10.1787/5kg9qx8dsx43-en

Hunt, A., & Ferguson, J. (2010). A review of recent policy-relevant findings from the environmental health literature. *OECD*. http://search.oecd.org/officialdocuments/displaydocumentpdf/?doclanguage=en&cote=env/epoc/wp nep(2009)9/final

Jain, V., Dey, S., & Chowdhury, S. (2017). Ambient PM2.5 exposure and premature mortality burden in the holy city Varanasi, India. *Environmental Pollution*, *226*, 182–189.

Jefferson, T., Demichelli, V., & Mugford, M. (2000). *Elementary economic evaluation in health care* (p. 148). BMJ Publications.

Jo, C. (2014). Cost-of-illness studies: Concepts, scopes, and methods. *Clinical and Molecular Hepatology*, *20*(4), 327–337.

Krewski, D., Jerrett, M., Burnett, R. T., Ma, R., Hughes, E., Shi, Y., Turner, M. C., Pope, C. A., III, Thurston, G., Calle, E. E., Thun, M. J., Beckerman, B., DeLuca, P., Finkelstein, N., Ito, K., Moore, D. K., Newbold, K. B., Ramsay, T., Ross, Z., Shin, H., & Tempalski, B. (2009). *Extended follow-up and spatial analysis of the American Cancer Society study linking particulate air pollution and mortality* (Vol. 140). Health Effects Institute.

Lepeule, J., Laden, F., Dockery, D., & Schwartz, J. (2012). Chronic exposure to fine particles and mortality: An extended follow-up of the Harvard Six Cities study from 1974 to 2009. *Environmental Health Perspectives*, *120*(7), 965–970.

Murray, C. J., Aravkin, A. Y., Zheng, P., Abbafati, C., Abbas, K. M., Abbasi-Kangevari, M., & Borzouei, S. (2020). Global burden of 87 risk factors in 204 countries and territories, 1990–2019: A systematic analysis for the Global Burden of Disease Study 2019. *The Lancet*, *396*(10258), 1223–1249.

OECD. (2014). *The cost of air pollution: Health impacts of road transport*. OECD Publishing.

Pearce. (2016). *Productivity losses and how they are calculated*. Cancer Research Economics Support Team (CREST).

Pohit, S., Singh, R., & Chowdhury, S. R. (2021). Role of policy interventions in limiting emissions from vehicles in Delhi, 2020–2030 [*ADBI Working Paper 1297*]. Asian Development Bank Institute. https://www.adb.org/publications/role-policyinterventions-limiting-emissions-vehicles-delhi-2020-2030

Pope, C., III Arden, Burnett, Richard T., Thurston, George D., Thun, Michael J. Calle, Eugenia E., Krewski, Daniel, & Godleski, John J. (2004). Cardiovascular mortality and long-term exposure to particulate air pollution: Epidemiological evidence of general pathophysiological pathways of disease. *Circulation*, *109*(1), 71–77.

Salvi, S., Kumar, G. A., Dhaliwal, R. S., Paulson, K., Agrawal, A., Koul, P. A., & Christopher, D. J. (2018). The burden of chronic respiratory diseases and their heterogeneity across the States of India: The Global Burden of Disease Study 1990–2016. *The Lancet Global Health*, *6*(12), e1363–e1374.

Son, J. Y., & Bell, M. L. (2013). The relationships between short-term exposure to particulate matter and mortality in Korea: Impact of particulate matter exposure metrics for sub-daily exposures. *Environmental Research Letters*, *8*(1), 014015.

The Economic Times. (2021). Delhi air pollution: SAFAR's advice can save people ₹7,694 crore annually on medical costs. Available at: https://economictimes.indiatimes.com/industry/healthcare/biotech/healthcare/delhi-air-pollution-safars-advice-can-save-people-rs-7694-crore-annually-on-medical-costs/articleshow/88048259.cms?from=mdr

Viscusi, W. K. (1993). The value of risks to life and health. *Journal of Economic Literature*, *31*(4), 1912–1946.

Wong, C. M., Vichit-Vadakan, N., Kan, H., & Qian, Z. (2008). Public Health and Air Pollution in Asia (PAPA): A multicity study of short-term effects of air pollution on mortality. *Environmental Health Perspectives*, *116*(9), 1195–1202.

World Bank. (2016). The cost of air pollution: Strengthening the economic case for action (English). World Bank Group.

World Health Organisation. (2015). Economic cost of the health impact of air pollution in Europe: Clean air, health and wealth. WHO Regional Office for Europe.