Air Quality and Cement Production: Examining the Implications of Point Source Pollution in Sri Lanka

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Abstract

Suspended particulate matter (SPM), dust, fumes and gases from cement production can result in a range of health effects to households living around factories. This study estimates the health costs associated with air pollution from a cement factory in the district of Puttalam in Sri Lanka. The study uses field data collected from 500 households living within a 3 km radius of the factory and measures seasonal air pollution to estimate dose-response functions and mitigation cost functions for different respiratory illnesses. The results indicate that the incidence of respiratory illness is about 14% amongst individuals who live in the vicinity of the cement factory**.** The study estimates that the expected annual welfare gain by reducing the SPM level by 50% is SLR 699 (US$ 7) per representative individual, while the annual welfare gain to all people living in the vicinity of the factory is SLR 2.96 million (US $ 29,600).

Key words: Air pollution, Dose response function, Mitigating cost function, Respiratory illnesses

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1. Introduction

Although air pollution is commonly associated with metropolitan areas, the problem is not uncommon in industrial locations of peri-urban and rural areas. Increased employment opportunities that are an inevitably by-product of industrial expansion motivate people to settle down close to factories. Even though some such jobs are risky and hazardous, households with few other alternatives accept them.

The cement industry in Puttalam, Sri Lanka, could be described as one such industry. It is an expanding localized industrial operation concentrated in areas with easy access to the basic raw materials, i.e., limestone and clay. These raw materials are found in abundance in the Northwestern coastal belt from Palavi in the Puttalam district up to Murugan in the Jaffna district. The demand for cement in Sri Lanka is increasing with rapid developments in the service and construction sectors. About 35% of this demand is met with domestic production. The Puttalam cement factory, which is the bigger of the two functioning factories, produces 80% of Sri Lanka's production of 542,000 MT (Economic and Social Statistics, 1998).

The processes of cement production, which comprise mining, pulverizing, grinding, and clinkering, generate air dust particulates, fumes, and gases consisting of Nitrous Oxide (NO), Nitrogen Dioxide (NO_2), Sulfur Dioxide (SO_2) and Carbon Monoxide CO. These emissions degrade the air quality in areas within 3-4 km radius periphery of the factory. Such emissions can contribute to a wide range of health effects, especially respiratory diseases, brain damage, lung cancer, heart diseases, skin irritations, fatigue, headache, and nausea (*World Development Indicators*, 2004). Failing eyesight due to fumes is also common in the operational area of the factory. According to the World Health Organization (WHO), long-term exposure to the above emissions can result in many diseases (see Appendix I).

The magnitude of any health impacts due to air pollution depends on the density of population, volume and concentration of emissions, temperature, wind direction, rainfall pattern, geographical conditions, and bio-diversity in the area. It also depends on the health stock of the people and their responses to pollution. However, it is also possible to improve existing emission-controlling systems or to introduce eco-friendly technologies in production. But reductions in emissions may result in an increase in the cost of production of cement. Such costs on the other hand could be off-set by improvements in labour and agricultural productivity as well as living standards of the local population. Accurate information on the magnitude of the impacts of air pollution, as well as the costs of air pollution abatement on the part of the cement industry, would therefore contribute towards the formulation of more efficient pollution abatement policies.

The main objective of this paper is to estimate the health benefits that would accrue from reducing the air pollution associated with cement production in Sri Lanka. We attempt this a) by estimating dose response functions of lower acute respiratory illnesses (LRI), upper acute respiratory illnesses

(URI), and all acute respiratory illnesses (ARI) for households living within 3 km from the cement factory; b) by calculating the mitigation cost functions associated with these diseases; and c) by measuring the welfare benefits to the households of reducing cement air pollution to a lower level.

2. Air Pollution and Health Impacts

Air pollution contributes to both morbidity and mortality. Over the last two decades, the impacts on pre-mature mortality have been well documented (*World Development Indicators,* 2004; Quah & Boon, 2002*;* Cropper, *et al.*, 1997; Ostro*, et. al.,* 1996; Dockery, *et. al.,* 1993; Ostro, 1995; Pope, *et. al.*, 1993). Dockery, *et. al.*, (1993), for example, showed that in Kingston, TN, the risk of early deaths in areas that have a high concentration of particulate air pollution (TSP) was 26% higher in comparison to areas with lower concentrations. In another study in six US cities, Schwartz (1996) found that the exposure to fine particulates ($PM_{2.5}$) was strongly associated with premature mortality while exposure to coarse particulates had little independent effect. Similarly, a study done in Santiago, Chile, (Ostro, *et. al.,* 1996) revealed that deaths from respiratory diseases and cardiovascular diseases were linked to exposure to small particles (PM_{10}). More pertinent to our work, is a study in Delhi, India, by Cropper, *et. al.,* (1997) who found that the impacts of air pollution on deaths were particularly high among aged 15-40 years people. Such results are reinforced by recent studies in the air pollution epidemiological literature (Quah and Boon 2002).

In addition to pre-mature mortality, there are morbidity effects associated with air pollution. Many studies show consistently higher rates of bronchitis and its symptoms among children with greater exposure to total suspended particulates (Alfesio L.F. Braga et al, 2001; Peters A. et al 1997; Dockery et. al., 1989). Aunan et. al. (1998) found in Hungary, for example, that the main benefits from reducing pollutants were the reduction in chronic respiratory diseases and maintenance costs for building materials. Recent studies in India (Gupta, 2006; Murthy *et. al.,* 2003) too highlight the link between air pollution and respiratory health. One of the few studies done in Sri Lanka by Chandrasiri (1999) suggests that vehicular emissions such as TSP SO_2, and O_3 are leading to morbidity effects among the local population in Colombo.

Health effects of air pollution carry tangible costs that individuals and households bear. In 1999, the total economic cost from air pollution in Singapore was estimated at US$ 3662 million or four percent of the country's GDP (Quah and Boon, 2002). A World Bank Study in China (1997) estimated that the cost of air pollution to China's economy was more than 7 percent of the GDP in 1995, largely due to health damages. In terms of household effects, Murty *et. al.,* (2003) estimate that the annual marginal benefit to a household from a reduction of SPM to a safe level is INR 2086 in Delhi and INR 950 in Kolkata. In another Indian study, Gupta (2008) has shown that the annual marginal health benefits gained by all citizens in Kanpur city from reducing air pollution to safe levels would be INR 213 million (US$ 5 million) or INR 79 (or US$ 2) per individual citizen.

In valuing environmental quality changes, economists prefer to use direct or indirect market values that reveal people's health preferences. There are many approaches to valuing health costs, which include methods such as defensive expenditure approach, cost of illness approach, health production function, productivity change method and the human capital approach. Each method has both advantages and disadvantages based on how available and good the underlying data are. In valuing the health impacts of air pollution, many researchers use the cost-of-illness

(COI) approach (Alberini and Krupnik, 2000). The method first establishes cause-effect or dose-response relationships and then values the impacts of environmental change. Several researchers (Alberini, *et. al.*, 1997; Ostro, 1995; Cropper, *et. al.*, 1997; Lvovsky, 1998; Quah, *et. al.*, 2002) have used dose-response functions in estimating morbidity and mortality related to air pollution. Stated preference approaches such as the contingent valuation method (CVM) are also used by some researchers (Halvorsen, B. 1996; Maddison D. 1997; Navrud S.1998). However, while they can be done, CVM studies are difficult to correctly implement in developing countries (Whittington 2002).

This study uses dose-response functions to estimate the respiratory illnesses caused by cement air pollution in Puttalam district. We then estimate mitigation cost functions to assess the welfare gains from a reduction in cement air pollution.

3. Study Area

Puttalam district is in the northwestern province of Sri Lanka. The climate in the district is tropical with a marked dry season with an average temperature of 27^0 C and an average annual rainfall less than 1000mm (see Appendix I). Administratively, there are 16 Divisional Secretary Divisions (DSD) and 548 Grama Niladhari Divisions (GND) in the Puttalam district while the cement factory is situated in the Palaviya G.S. division, which is 8 km from Puttalam town. The cement industry could be described as the only industry that affects ambient air quality in the locality.

The Puttalam cement factory was established in the 1970's due to the availability of raw material. The population density of the area was low at the time of establishment. However, the population since then has increased due to both infrastructure development and increased employment opportunities in the factory. According to the Department of Census and Statistics (2005), the increment is about 7 fold since the '70s. The factory produces more than 30 percent of the cement demand of the country and contributes to more than 80 percent of the local production, i.e., it is the largest cement producer in the country. The Swiss company, Holcim Group, owns the factory at present and employs about 2000-2500 workers mostly on a contract basis. The factory management assists the locals when it comes to certain social issues such as education, health and community welfare.

The local population claims that cement dust poses a health hazard to them (Reports of the Wayamba Environmental Authority, 2003 and 2004, and Central Environmental Authority, officers[1]). Reports also indicate that local people had protested against the factory a few times during the 2001-2005 period for dust impacts. Although a certain level of visible dust was mitigated with the new technology established at the factory 4 to 5 years ago, the severity of respiratory illnesses appears to persist. Our primary motive in the study is to examine this problem.

4. Data

As the study aims at measuring the impacts on respiratory illnesses of cement air pollution and at estimating the welfare gains, we needed to collect data on household information, pollution measurements and certain abatement costs associated with the cement factory. For the purpose of collecting household and pollution data, we first demarcated the affected area as a 3 km radius

[1] Personal communications with government officers of the area.

distance area around the factory. To accomplish this, we obtained the assistance of the National Building Research Organization (NBRO), a government organization involved in measuring air pollution levels in major towns and chemical industries in the country. We then divided the 3 km area into six strata of 0.5 km distance each from the cement factory utilizing available information on population density and other environmental and physical factors (see Figures 1a and 1 b).

Based on the total population of the demarcated study area (1058 households), we randomly selected 500 households within each stratum for the household survey (see Table 1). The co-investigator and research assistants conducted household interviews using a pre-tested questionnaire via personal visits to the selected households during two seasons: wet and dry.

We collected household data during the months of December 2005 for the wet season and June 2006 for the dry season. The data collected included information on household characteristics, socio-economic factors, and health and medical information, especially on respiratory illnesses and symptoms, for each individual in the household. We requested the residents to recall respiratory illnesses on two bases — the previous year illnesses and the illnesses within the last two weeks. We used the data based on 'two weeks recall' for the econometric analyses that follow while and the impact of the previous year's illness appears as an independent lag variable (see Appendix I). We attach the questionnaire used for collecting household data as Appendix II.

NBRO obtained pollution data by measuring air quality at 0.5 km distance from the factory in 10–12 locations during the wet and dry seasons paying particular attention to wind direction. The researchers undertook measurements of pollutants using a measurement device (see Figure 3), which was located and operated for 24 hours under the supervision of a well-trained enumerator of NBRO, in order to measure pollution levels of SPM, NO_2, SO_2 and CO (see Table 2). We took all the pollution measurements on two consecutive days in order to minimize variance. We assigned the pollution data to each household in the analysis based on proximity to the particular location (see Figure 1c, 1d). We could not however measure pollution levels for each household separately because the cost of measurement was high due to constraints imposed by time and apparatus. Thus, in the absence of household-specific pollution information and regular government monitoring of air quality, we had to generate air pollution data for specific points and seasons around the factory. We were unsuccessful in obtaining data related to the abatement efforts of the factory despite repeated discussions, meetings and telephone conversations with the senior management of the factory.

Air pollution results show that the pollution levels are below the ambient air standards of Sri Lanka in 1994 (these standards are however controversial) but are significant compared to WHO and Indian standards (see Appendix I). The SPM level is the most significant, especially in the wet season when SPM is significantly higher than WHO standards. The average SPM, SO_2 and NO_2 levels of the study area are 80.8, 20.2 and 24.7 µg per cubic meter. A specific pattern of SPM levels or other pollutants in relation to wind direction is not obvious – perhaps due to wind circulation in the area.

The general characteristics of the entire sample of the households indicate an average family size of 6 persons per household in the area with a mean age of 32 years and an education level of grade 4. Nearly 23% of the households reported no schooling and another 77% reported only primary education levels. These education levels are low compared to many other districts and in comparison with national indicators (Department of Census and Statistics, 2005). The three main occupations in this area are employment in the private or government sector, farming, and temporary sundry labour. Nearly 6% of the households have at least one individual working in the cement factory. Of the total number of households, roughly 24% were employed in government or private sector enterprises, while the majority was engaged in agriculture. A smaller percentage was found in temporary labour.

The average monthly income of an average household was around SLR 10,910 with an agricultural income of SLR 730. Since the average household income in Sri Lanka for 2004 was SLR 15,405 (Central Bank, 2004), the result suggests that the households in this area are relatively poor. The average monthly family expenditure was around SLR 7200 of which the food expenditure amounted to 88% of the total. The mean value of all assets owned by a household was around SLR 121,900, to which the value of land contributed around 77% (see Table 3). Nearly 67% of the households used firewood, 13% kerosene and 15% LPG as a source of energy for cooking. Of these, 72% households ventilate through kitchen windows while 21% do so by means of the kitchen chimney. Nearly 7% of households did not have any form of kitchen ventilation (see Table 4).

We asked numerous health related questions. Medical information on the previous year (2005) indicated that Bronchitis, Pleurisy, high blood pressure, and heart trouble were significant in the sample households. Nearly 15 % of individuals indicated that they had suffered from these diseases during the previous year. Data on symptoms and illnesses related to respiratory illnesses based on 'two weeks recall' showed that nearly 10.1% of individuals suffered shortness of breath, 11.1% cough/phlegm, 1.3% Asthma and 0.8% heart problems (see Table 5). The average individual of the sufferers in our sample incurred a total medical cost of SLR 3402 over a 12 months period as a result of all respiratory symptoms.

Our data also show that the smoking habit among males is quite significant with the average age of a smoker at 20 years, with daily consumption ranging from 4-5 cigarettes and incurring a monthly expenditure of SLR 465 per household.

5. Methodology

The study uses the household production function model to estimate the economic benefits from reduced morbidity due to reduction in air pollution in the Puttalam district in Sri Lanka. We base the household health production function and the demand for mitigating activities that are implicit in the utility maximizing behavior of an individual on Freeman's (1993) derivations as given below:

An individual's utility function may be defined as,

$$U = U(X,L,H) \qquad (1)$$

Where, X is the consumption for market goods; L denotes leisure; and H represents the health condition due to air pollution. Here, $\frac{\partial U}{\partial X} > 0$, $\frac{\partial U}{\partial L} > 0$, and $\frac{\partial U}{\partial H} > 0$. The health production function is given by:

$$H = H(A,Q,B)\,H \qquad (2)$$

where A is avertive activities; Q is pollution and B is medical or mitigating treatment. Avertive activities refer to actions taken by the individual to avert the impacts of air pollution on health. Mitigating activities are actions taken to decrease the impacts and include medical costs.
The budget constraint can be expressed as

$$I + w(T - L) = X + P_{\alpha}.A + P_{b}.B \qquad (3)$$

where, I is the non wage income; T is total available time; P_a is the price (unit cost) of pollution avertive activities; P_b is the price (unit cost) of medical treatment. Here X is treated as a numeriare good (i.e., a good with the price of one). The individual selects X, L, A and B to maximize his/her utility (1) subject to (3).

The simultaneous solution to the first order conditions of this utility maximization problem establishes the demand for the composite commodity, leisure, mitigation activities and medical treatment. For example, the demand functions for avertive activities (A) and medical treatment (B) could be given as,

$$A = A(I, w, P_a, P_b, Q) \quad \text{(4)}$$

$$B = B(I, w, P_a, P_b, Q) \quad \text{(5)}$$

Simultaneous estimation of the health production function and demand functions A and B would allow us to determine the marginal willingness to pay for reduction in air quality improvements (Freeman, 1993):

$$MWTP = w.\frac{dH}{dQ} + P_a\frac{\partial A}{\partial Q} + P_b\frac{\partial B}{\partial Q} + \frac{\partial U}{\partial H}\frac{dH}{dQ}\frac{1}{\lambda} \quad \text{(6)}$$

Equation (6) shows that *MWTP* for health benefits from reduction in pollution is the sum of observable reduction in time cost of illness, cost of avertive and mitigating activities and the monetary equivalent of the disutility of illness.

Alternatively, we could estimate a reduced form dose response function with health as a function of pollution and other variables. We could combine this with the estimated demand for mitigating and/or avertive activities and wages to obtain a lower bound for equation (6). This is a lower bound estimate, as it does not take into consideration the disutility of sickness, i.e., $\frac{\partial U}{\partial H}\frac{dH}{dQ}\frac{1}{\lambda}$.

In our study, our data allows us to estimate two equations: the health production function or dose response function and the mitigating expenditure or medical costs function. We do not estimate avertive costs because we were unable to obtain credible and adequate information on avertive costs through our household survey. We are also unable to estimate the disutility generated from sickness – this information is difficult to assess accurately and we do not do so. Thus, we estimate a lower bound for the marginal willingness to pay for reductions in air pollution.

5.1 Estimations of Dose Response Functions

The dose response function indicates the extent to which different diseases respond to various pollutants after controlling for other factors. In our study, the dependent variable used in the dose response function is presence of upper or lower respiratory illnesses ($Pr = 1$) or not ($Pr = 0$) among individuals during a two-week period prior to the 2005/2006 household survey.

A Logit model (Greene, 1993) is used to estimate the parameters of the dose-response function. The logistic distribution is of the form,

$$\Pr(y=1) = \frac{e^{X'\beta}}{1+e^{X'\beta}} = \Lambda(X'\beta) \quad \text{(7)}$$

where $\Lambda(\cdot)$ indicates the logistic cumulative distribution function and X includes a vector of exogenous variables (defined below). The logistic distribution gives large probabilities to $y = 0$ wher $X'\beta$ is extremely small and smaller probabilities to $y = 0$ when $X'\beta$ is much larger than the normal distribution.

Thus, in the Logit model the partial derivatives are not the marginal effects and it varies with the values of X as indicated below:

$$\frac{\partial E(y|X)}{\partial X} = \Lambda(X'\beta)[1-\Lambda(X'\beta)]\beta \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (8)$$

The dependent variables refer to two types of respiratory illnesses (upper and lower), which were identified based on a series of symptoms. We identified Upper Acute Respiratory Illnesses (URI) based on symptoms of sore throat, running or blocked nose/sinusitis, ear infection (ear ache), sudden high fever, cough while lying down, headache, irritability or fatigue. We associated Lower Acute Respiratory Illnesses (LRI) with persistent cough with mucus, pneumonia, chest congestion, wheezing in chest, chest pain while breathing and asthma. We were able to consider all respiratory illnesses (ARI) by combining both the LRI and URI. The dataset is based on individual data. It covers 3490 individuals in 500 households over two seasons.

5.2 Estimation of Mitigation Cost Functions

The mitigating expenditure function represents the relationship between medical and other mitigating expenditures undertaken by individuals and air pollution with controls for other variables. The dependent variable, mitigating expenditure, is a censored variable in our study sample. Censoring occurs when the dependent variable corresponding to known values of independent variables is zero for part of the sample. Because of the large number of zero values in our dataset for medical expenditures, we use the Tobit model for estimating the demand function for mitigating activities. Thus,

$$y^*_{it} = \begin{cases} \alpha + \beta X_{it} + u_i & if \quad y > 0 \\ 0 & otherwize \end{cases} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (9)$$

where, y^*_{it} refers to the probability of the *ith* household incurring positive mitigating expenditure at time *t*, and X_{it} denotes a vector of individual characteristics, such as income, age and education, pollution parameters, weather conditions, etc. For the index variable, the marginal effect is defined as $\frac{\partial y^*_{it}}{\partial X_{it}} = \beta$ while for the original variable is as $\frac{\partial y^*_{it}}{\partial X_{it}} = \beta$ (probability of $y^*_{it} > 0$).

The data refers to mitigation expenditure incurred by 508 individuals in 500 households. Mitigating expenditure includes doctors' fees, medicine costs, transportations costs to the dispensary or hospital, and the time cost of the caretaker. We based the time cost on the caretaker's profession. We did not consider the time cost when the caretaker was unemployed (see Appendix I). The data on mitigating expenditure for upper or lower respiratory diseases comes from the 2005/2006 wet and dry season surveys. The data cover 3490 individual observations over the two seasons.

5.3 Empirical Specifications

The following reduced form equations of the dose response and mitigating cost functions are estimated for upper respiratory illnesses (URI) and lower respiratory illnesses (LRI) as well as all respiratory illnesses (ARI) for the wet and dry seasons of 2005/2006.

The dose response function is:

$$pr(1,0) = \alpha_0 + \alpha_1 SME + \alpha_2 Ed + \alpha_3 Age + \alpha_4 NHS + \alpha_5 In + \alpha_6 S + \alpha_7 SPM + \alpha_8 SO_2 + u \text{ ...(10)}$$

The mitigation cost function is:

$$MC = \beta_0 + \beta_1 SME + \beta_2 Ed + \beta_3 Age + \beta_4 NHS + \beta_5 In + \beta_6 S + \beta_7 SPM + \beta_8 SO_2 + v \text{ .... (11)}$$

The independent variables are identical in both equations. The definitions of the dependent and independent variables are as follows:

Probability of a disease *Pr* (1,0): This represents the incidence of URI, LRI and ARI, (*Pr* = 1) or not being infected with any respiratory illness (*Pr* = 0) amongst individuals;

Mitigation cost (MC): Mitigation cost represents the amount of expenditure incurred by the individuals of the households for treatment of URI, LRI, and ARI (SLR/person) incurred due to air pollution.

The dependent variables are based on: a) individual data from the household surveys; and b) pollution data. They include:

Smoking expenditure (SME): This represents the smoking expenditure incurred by individuals in the household in SLR/month.

Education level (Ed): The education level is measured as the grade of education received by each individual of the household. Education levels vary from no schooling (grade 0) to grade 12.

Age (Age): Dummy variable representing age = 1 for individuals when the age is higher than 55 years or less than 15 years; age = 0 for individuals who are between 15-55 years.

Negative health stock of last year (NHS): Dummy variable representing the presence of respiratory diseases in 2005. Here NHS=1 if the individual suffered from any respiratory diseases and NHS=0 if there was no occurrence of a respiratory disease.

Income (In): This refers to individual monthly income in SLR. When an individual did not earn income, this takes the value zero.

Season (S): Dummy variable representing the wet (September – March, 2005) and dry (April-August, 2006) seasons of the year in the district. Here S=1 for the wet season and S=0 for the dry season.

Suspended Particulate Matter (SPM): This is the value of SPM closest to the household location in microgram/m^3 as measured by the National Building Research Organization (NBRO) for wet and dry seasons separately. SPM that is released during cement manufacture remains in the atmosphere because of its low settling velocity. It can penetrate deeply into the respiratory system and cause upper and lower respiratory illnesses to humans.

Sulphur Dioxide (SO_2): This is the value of the SO_2 gas emission during cement production as measured by NBRO as nearest to the household residence in microgram/m^3 for wet and dry seasons separately. This emission is included in the equations in interaction with the levels of SPM.

5.4 Calculation of Welfare Gains

Our welfare estimates of the impact of air pollution include only the medical expenditure incurred by individuals and do not include sick day wage losses. While we do estimate the dose-response function, we found that there were no sick days lost as a result of air pollution and thus were not able to include these numbers in our analyses. Thus, we calculate the annual welfare effect from reductions in current SPM levels based on the estimates of the SPM coefficient from the medical expenditure (mitigating cost) equations.

Given mean mitigation cost of the two seasons (MC), mean SPM level of the two seasons (SPM) and, $\frac{\partial MC}{\partial SPM}$ (marginal effect)= $f'\beta i$, where f' = Prob Yi > 0(number of observation which are non-zero/total number of observations in the sample):

Reduction of MC by reducing SPM to a safe level (ΔSPM) from the current level

$$= f' \beta i * \Delta SPM$$

Reduction of MC per year by reducing SPM to a safe level from the current level

$$= f'' \beta i * \Delta SPM * 26$$[2]

6. Results and Discussions

In the sections below we discuss the results from the dose-response functions as well as the mitigation expenditure functions.

6.1 Reduced Form Dose Response Functions

Table 6 shows the summary statistics of the variables regressed in the dose response equations and Table 7 shows the results of the reduced form equations for the dose response equations for ARI, URI and LRI among households in the Puttalam district. The probability of diseases was fitted as a function of pollution and socio-economic variables for Logit estimation of the ARI, URI and LRI equations. In all three estimations, SPM, smoking expenditure, lagged health stock, and income were significant with the expected signs. Other variables were with expected signs but not significant.

The key variable of interest to us is SPM. SPM has a significant effect on all three respiratory illnesses. An increase in SPM contributes to an increase in the probability of ARI, LRI and URI.

Smoking expenditure, as expected, has a significant positive effect on ARI, LRI and URI. The lagged negative heath stock variable was significant in all illnesses. As the variable measures the presence of disease in the previous year, the probability of occurrence of respiratory illnesses in the current year (2006), increases if individuals had a respiratory problem in the previous year. The negative sign of the seasonal dummy indicates that the wet season has a higher probability for respiratory illnesses. As expected, SO_2 has a positive impact on the presence of respiratory illnesses in all three groups.

6.2 Reduced Form Mitigation Cost Functions

We show the estimated coefficients for selected mitigation cost functions for ARI, LRI and URI (after checking for all possible independent variables like rainfall, wind direction, household characters, etc.) models in Table 8.

In the results for three equations, coefficients of independent variables SPM, smoking expenditure, monthly income and lagged negative health stock were significant with expected signs. As

[2] We multiply by 26 because the mitigation cost data was obtained in our survey for every 2 weeks.

expected, the mitigation cost of ARI, URI and LRI increases with an increase in the SPM pollution level. Similarly, a higher expenditure for smoking increases the mitigation costs of all respiratory diseases. The significant and positive relationship between income and costs of ARI, LRI and URI suggest that richer individuals obtain more medical treatment. The negative health stock of the previous year has a significant influence on the mitigation cost of ARI, URI and LRI for the current year. As the variable measures the presence of respiratory diseases in the previous year, the mitigation cost increases in the current year. The expected sign of the seasonal dummy indicates that mitigation costs for all diseases are higher in the wet season (when there is more sickness) compared to the dry season. As expected, mitigation cost of all the diseases seems to increase with an increase in the SO_2 level.

6.3 Welfare Gains

Table 9 shows the welfare effect for the study area when we reduce by various levels the current SPM level. For instance, if the current SPM level is reduced by 50% (i.e., to 0.040mg/m3), a family living within 3 km from the cement factory would benefit by about SLR 2796 (US$ 28) per year. The welfare gain through reductions in ARI for all the 1058 households living within 3 km of the factory is SLR 2.96 million (US $ 29,600) per year. The assumption here is that the average family has 4 members. This gain would be higher if we could include the costs of lost working days and missing activities as well as other impacts through pain and discomfort. Since there were no data on the lost working days of an individual due to air-pollution-related illnesses, savings in wage losses could not be estimated. Our welfare estimates as a result are very conservative estimates of the gains from reduced air pollution.

7. Conclusions and Policy Implications

The study indicates that there are significant health impacts due to cement air pollution on the locals living within 3 km of the cement factory in Puttalam. Susceptibility to respiratory illness and costs associated with it seem to be higher in the wet season due to higher SPM levels.

Reducing the current SPM levels of cement air pollutants in significant margins could reduce the mitigation cost of respiratory illnesses immensely, which would in turn lead to welfare gains for the entire society. For instance, reduction in SPM levels by 50% would lead to a gain of SLR 699 (US$ 7) per representative individual while the annual welfare gain to all people within the 3 km region would be approximately SLR 3 million. A 100% reduction in SPM levels would meet WHO standards. This would lead to an annual gain per individual of SLR 1398 (US$ 14) with the annual gain to the community being approximately SLR 6 million. These numbers compare well with Gupta's (2008) study. She estimates that reducing PM10 to safe levels would save each individual in Kanpur, India, one dollar per year in medical costs and another dollar per year in terms of wages gained because workers would not lose workdays due to sickness.

Compensating affected individuals for their health losses would be one option in order to overcome damages to the households. However, it might be less expensive for the factory to bring in technology to abate air pollution. Studies such as ours also suggest that Sri Lanka needs to revise its air pollution standards. We expect the present study to inform policy makers about the tangible health costs that individuals bear due to air pollution so that they can see that it is reasonable to revise existing standards.

This study is a first attempt to bring together socio-economic and pollution data in order to understand the links between air pollution and health in Sri Lanka. It therefore suffers from limitations that could be improved in future research. For example, the inclusion of lost productivity in the surveyed population could improve the estimations of health cost. Moreover, inclusion of information on abatement costs of the factory would help determine the net benefits of abating pollution. This information was unavailable to us. The data on air quality was also limited. Daily data on air quality would make the estimations more credible. On the other hand, this study could be seen as an example of how health costs can be assessed in developing countries even in situations of limited information.

8. Acknowledgements

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TABLES

Table 1: Sampling of Households for the Socio-economic Survey

Distance from cement factory (Km)	0-0.5	0.5-1	1-1.5	1.5-2	2-2.5	2.5-3
Total households	09	29	84	133	297	506
Sample size	05	15	40	62	140	238
Sample % of total Households	47	47	47	47	47	47

Table 2: Air Pollution Levels within 3Km Distance of Cement Factory, Puttalam District (National Building Research Organization (µg /m^3)

Dis. from CF (km)		**Wet Season**			**Dry Season**		
Location	Ave. time (hours)	SPM µg/m3	SO2µ-g/m3	NO2 µg/m3	SPM µg/m3	SO2 µg/m3	NO2 µg/m3
1 - (L1-0.5km)	24	144	14	24	107	22	22
2 -(L2-0.75km)	24	219	13	50	121	20	23
3 -(L3-1km)	24	112	17	32	098	24	23
4- (L4-1.5km)	24	095	19	02	094	47	34
5 -(L5-2km)	24	076	45	23	073	22	24
6 -(L6-2km)	24	057	14	20	047	23	24
7 -(L7-2km)	24	055	32	29	068	17	21
8- (L8-2.5km)	24	130	09	29	045	15	14
9 -(L9-3km)	24	126	01	33	025	33	19
10- (L10-3km)	24	125	14	29	039	14	32

Table 3: General Characteristics of the Surveyed Households

Item	Mean	Std. Deviation	Min	Max
Average family size	4.0	1.06	2	6
Average area of the house (m2)	29.5	8.09	0	60
Average age of household individuals (yrs)	31.99	17.28	0.3	88.0
Education level (grade)	4.09	1.04	0	11.0
Private and public sector employment (%)	24			
Public sector employment (%)	2.0			
Own farm agriculture (%)	1.1			
Off farm agriculture (%)	3.9			
Size of home garden (perches)	0.678	0.576	0	9.50
Total value of household assets (SLR)	121909	27020	0	250501
Land value per household (SLR)	94289	198101	0	300,000
Wealth (SLR)	67646.4	199675.3	0	3227000
Smokers (%)	12.26			
Expenditure for smoking/month (SLR)	465			
Alcohol consumers (%)	4.52			
Expenditure for alcohol/month (SLR)	236.7			

Table 4: Kitchen Characteristics (Indoor Air Pollution)

F/W	LPG	Kerosene	Other	Window	Chimney	None
67.67	12.66	14.66	5.00	71.60	22.00	7.30

Table 5: Respiratory and Related Diseases among Surveyed Households

Illness over last 12 months	**% of individuals reported**	**Mitigation cost/person (Rs)/year**
Bronchitis	3.26	2473
Pleurisy	2.69	6185
High Blood Pressure	2.12	4535
Chronic Bronchitis	0.17	1933
Pneumonia	0.12	2510
Heart Trouble	3.95	3137
Other Lung Diseases	0.12	3000
Illness /Symptom over last two weeks		
Shortness of Breath	10.14	
Cough/Phlegm	11.11	
Asthma	1.26	
Heart Injuries	0.8	

Table 6: Summary Statistics of the Regression Variables

Variable	**Obs**	**Mean**	**Std. Dev.**	**Min**	**Max**
Smoke exp (SLR)	3490	133.46	378.07	0	3000
Edu (grade)	3490	4.08	1.409	0	11
Age (dummy)	3490	0.2993	0.4556	0	1
Health Stock (dummy)	3490	0.1535	0.3600	0	1
M. income (SLR)	3490	3126.33	5456.17	0	80000
Season (dummy)	3490	0.5	0.5000	0	1
SPM (mg/m^3)	3490	0.080	0.042	0.025	0.219
SO2 (mg/m3)	3490	0.0202	0.0109	0.001	0.057

Table 7: Estimated Coefficients for Dose Response Functions for ARI, LRI and URI

Dependent Variable: Probability of diseases (1,0) Logit function
Mean Probability: ARI = 0.141, URI= 0.126, LRI = 0.024

Independent variable	**ARI**	**LRI**	**URI**
Smoking exp (SLR/month)	0.0005*** (0.0001)	0.0003* (0.0002)	0.00058*** (0.0001)
Education (grade)	0.0084 (0.0359)	(0.0991) (0.0734)	0.01692 (0.0386)
Age (dummy)	-0.1457 (0.1165)	0.2605 (0.2367)	-0.2047* (0.1260)
Negative Health Stock of last year (dummy)	1.2174*** (0.1142)	1.1617*** (0.2324)	1.2086*** (0.1203)
M.Income (SLR)	0.00002*** (8.07e-06)	0.00004*** (0.0000)	0.00001* (8.36e-06)
Season (dummy)	-0.1657 (0.1755)	-0.0656 (0.3727)	-0.1593 (0.1887)
SPM (mg/m^3)	**4.4019*** (1.8414)**	**6.5021* (3.6961)**	**3.7651** (1.9743)**
SO2 (mg/m^3)	5.7020 (5.5272)	14.5920 (11.5165)	2.7128 (5.9837)
Constant	-2.5227*** (0.2479)	-5.4121*** (0.5308)	-2.6361*** (0.2664)
Log likelihood	-1396.65	-411.81	-1254.59
N	3490	3490	3490
* Sig @ 10%, **sig @ 5%, ***sig @1%, figures in parentheses are the standard errors			

Table 8: Estimated Coefficients of the Mitigation Cost Functions for ARI, LRI and URI (Tobit Analysis)

Dependent Variable: Mitigation cost of ARI, LRI and URI in (Rs).
Mean (Rs/month): ARI = Rs.115.05, URI= Rs. 103.58, LRI = Rs. 12.83

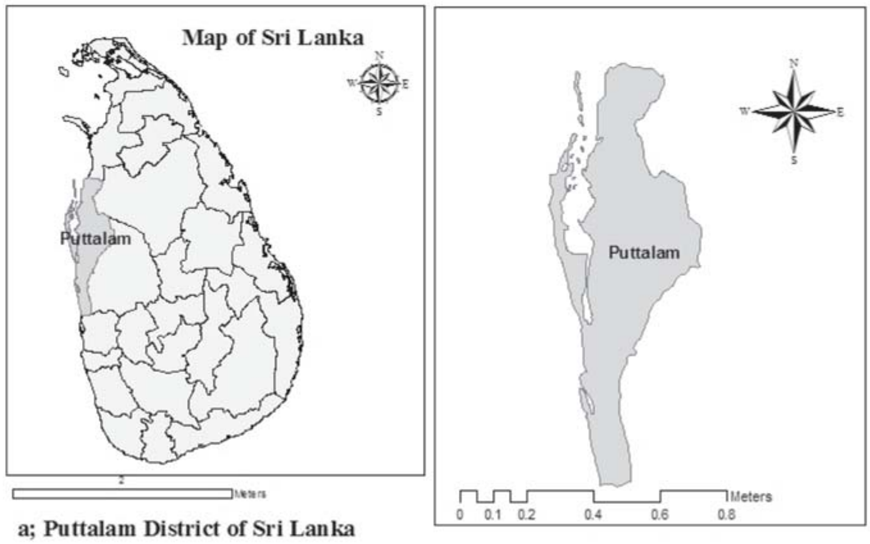
Independent variable	**ARI**	**LRI**	**URI**
Smoking exp (SLR/month)	0.6137*** (0.1500)	0.2506** (0.1235)	0.6433*** (0.1589)
Education (grade)	15.2965 (44.8375)	62.1696* (36.4562)	14.5839 (48.1866)
Age (dummy)	-114.5835 (146.4894)	102.1859 (124.245)	-134.0764 (156.2598)
Negative Health Stock of last year (dummy)	1368.96*** (159.9084)	547.04** (138.2153)	1365.55*** (170.07)
M. Income (SLR)	0.0260*** (0.0101)	0.0177*** (0.0071)	0.0237** (0.0108)
Season (dummy)	-228.5362 (226.077)	-299.049 (211.10)	-94.4145 (238.105)
SPM (mg/m^3)	**5639.58***** **(2398.18)**	**4375.43**** **(2113.88)**	**4833.41**** **(2532.92)**
SO2 (mg/m^3)	10111.85 (7161.08)	4591.81 (6255.42)	10102.07 (7624.98)
Constant	-3708.66*** (336.6049)	-3161.25*** (406.948)	-3938.18*** (363.16)
Log likelihood	-5423.77	-1027.02	-4921.58
N	3490	3490	3490
* Sig @ 10%, **sig @ 5%, ***sig @1%, figures in parentheses are the standard errors			

Table 9: Welfare Gain of Community through MC with Various Reductions in Current SPM level per Annum

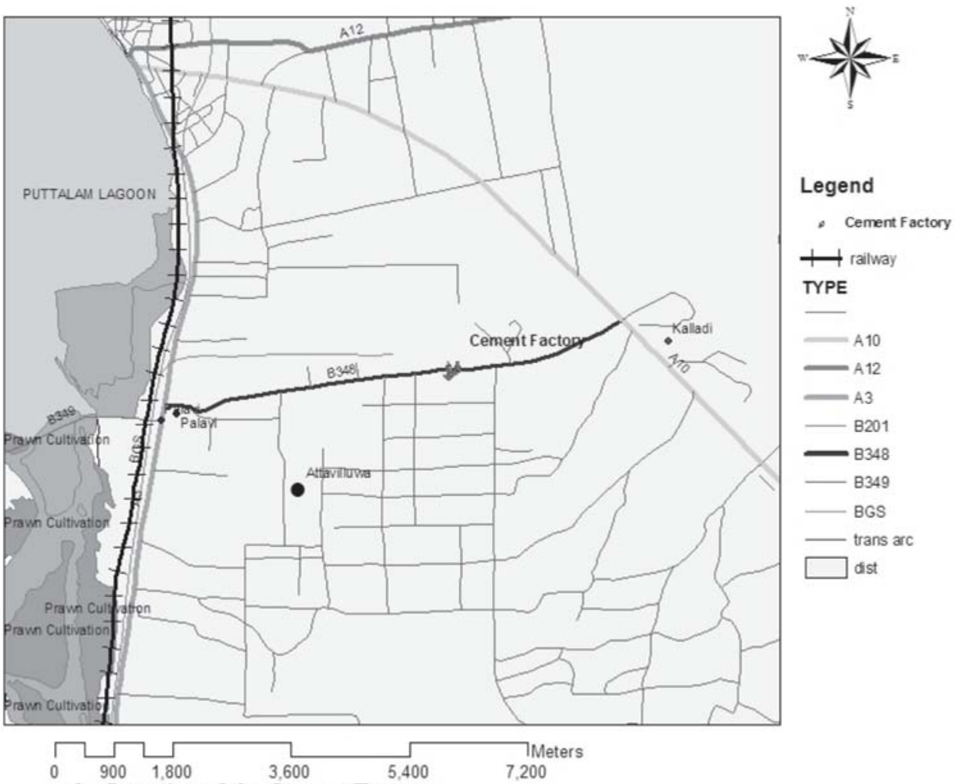
Distance from CF -Km	**Reduction levels of current SPM (%)**	**Welfare gain on individual basis(SLR)**	**Welfare gain at household level (SLR)**	**Welfare gain to the community (SLR million)**
0-1.5	25	523	63,806	0.25
	50	1048	127,856	0.51
	75	1,571	191,662	0.77
	100	2,095	255,590	1.02
1.5-3.0	25	349	326,664	1.30
	50	628	587,808	2.35
	75	942	881,712	3.52
	100	1,256	1,175,916	4.71
0-3.0	25	349	369,242	1.47
	50	**699**	**739,542**	**2.96**
	75	1,048	1,108,784	4.35
	100	1,398	1,479,084	5.91

FIGURES

Figure 1: Study Area in Puttalam District if Sri Lanka

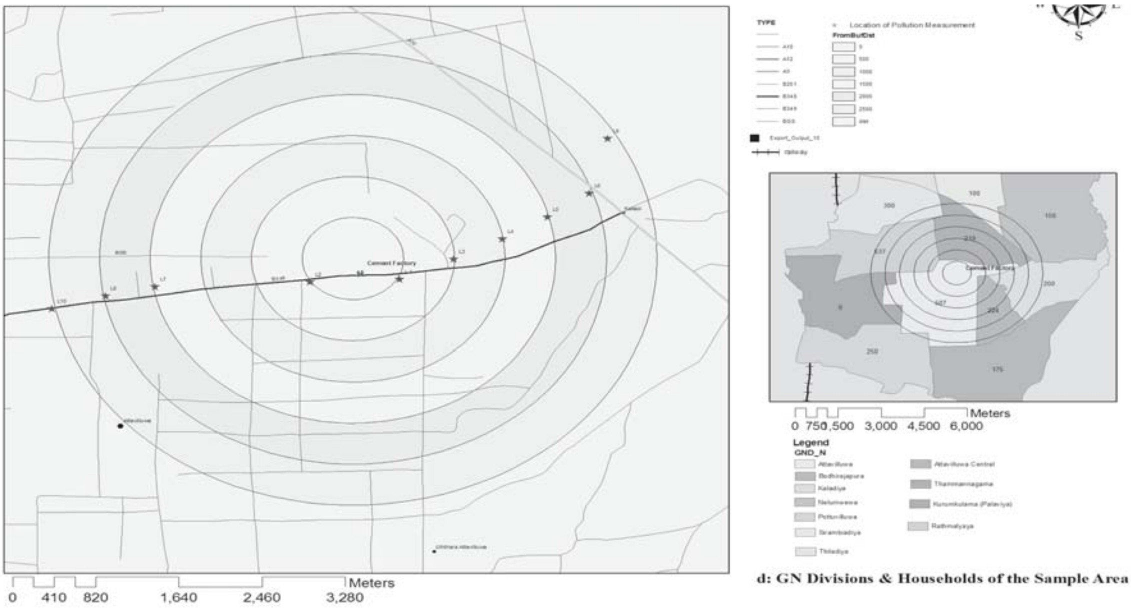


a; Puttalam District of Sri Lanka



b: Location of the Cement Factory

Figure 2: Air Pollution Collection Locations



c: Locations of Pollution Measurements & Sample Area

d: GN Divisions & Households of the Sample Area

Figure 3: Device for Air Pollution Measurement

APPENDIX 1

Table 1: Ambient Air Quality Standards of WHO

Pollutant	Primary Stds.	Averaging Times	Secondary Stds.
Carbon Monoxide	9 ppm (10,000μg/m^3)	8-hour	None
	35 ppm (40,000 μg/m^3)	1-hour	None
Lead	1.5 μg/m^3	Quarterly Average	Same as Primary
Nitrogen Dioxide	0.053 ppm (100 μg/m^3)	Annual (Arithmetic Mean)	Same as Primary
Particulate Matter (PM_{10})	50 μg/m^3	Annual (Arithmetic Mean)	Same as Primary
	150 ug/m^3	24-hour	
Particulate Matter ($PM_{2.5}$)	15.0 μg/m^3	Annual (Arithmetic Mean)	Same as Primary
	65 ug/m^3	24-hour	
Ozone	0.08 ppm	8-hour	Same as Primary
Sulphur Oxides	0.03 ppm	Annual (Arithmetic Mean)	
	0.14 ppm	24-hour 3 hour	0.5 ppm (1300*1000 μg/m^3)

Table 2: National Ambient Air Quality Standards (NAAQS) - India

Pollutant	Ambient Air Quality		Sensitive Area
	Industrial Area	Residential, Rural and other areas	
SO2 (24 hours)	120μg/m^3	80μg/m^3	30μg/m^3
NO2 (24 hours)	120μg/m^3	80μg/m^3	30μg/m^3
SPM (24 hours)	500μg/m^3	200μg/m^3	100μg/m^3
CO (8 hours)	5.0mg/m^3	20mg/m^3	0.4mg/m^3

Table 3: Average Temperature (C^0) in Puttalam District

Month	Ave-2004	Ave-2005	Ave-2006
Jan	27.2	26.4	25.1
Feb	27.2	27.75	26.6
March	28.6	29.8	27.7
April	29.15	29.15	28.85
May	28.65	30.05	29.25
June	28.7	29.65	29
July	28.55	29.15	
Aug	29.1	30	
Sept	28.5	29.7	
Oct	27.8	28.6	
Nov	27.05	26.6	
Dec	26.1	26.1	

Source: Department of Meteorology, Sri Lanka

Table 4: Average Relative Humidity of Puttalam District, %(2004-2006)

RH- Puttalam District			
Month	**Ave-2004**	**Ave-2005**	**Ave-2006**
JA	84.5	86	85.5
FE	77.5	78.5	82.5
MA	78	77.5	85.5
AP	81	82	84
MAY	84.5	79.5	83
JU	82.5	77.5	83.5
JY	81	76	
AU	77	73.5	
SE	81	73	
OC	84.5	82	
NO	89	89	
DE	88.5	86	

Source: Department of Meteorology, Sri Lanka

Table 5: Average Rainfall (mm) Pattern in Puttalam District, (2004-2006)

Rainfall- Puttalam District			
Month	**Ave-2004**	**Ave-2005**	**Ave-2006**
Jan	4.7	49.6	128.9
Feb	2.6	0	35.3
March	44.8	68.3	229.3
April	112.7	113.3	64.7
May	212.1	42.3	85
June	69.4	2.4	5.3
July	1.9	52.6	
Aug	2.5	12.1	
Sept	87.2	0	
Oct	279	314.7	
Nov	283.9	339	
Dec	119.1	104.5	

Source: Department of Meteorology, Sri Lanka

Table 6: Comparison of Measured Pollution Levels with Ambient Air Quality Standards of Sri Lanka, India (NAAAQS) and World Health Organization (WHO)

Pollutant (for 24 hours period)	**Mean values** of the Study area	**S/L Standards**	**India** (Residential, rural & other areas)	**WHO Standards**
SPM- $\mu g/m^3$	80.4	300	200	-
PM10 - $\mu g/m^3$	45.6	-	-	150
NO2- $\mu g/m^3$	26.2	22.8	80	100 (annual arithmetic mean)
SO2 - $\mu g/m^3$	22.1	80	-	140ppm

Table 7: Annual Mitigation Costs of ARI, URI and LRI of Households (Rs) for the year 2005

Respiratory Diseases	Minimum	Maximum	Mean	Standard Deviation
All (ARI)	0	120,000	465.08	3592.84
Upper (URI)	0	19,000	105.92	784.11
Lower (LRI)	0	2,200	11.09	91.07

Table 8: Total Mitigation Expenditures (SLR) for Both Seasons in Rupees (two week recall)

Season	Illness	Doctor visit	Transport + care taker	Total expenditure
Both	URI	187,106	162,815	349,921
	LRI	12,100	29,900	42,000
Dry	URI	76,070	78,000	154,070
	LRI	6,200	16,250	22,450
Wet	URI	111,036	84,815	195,851
	LRI	5,900	13,650	19,550

FIGURES

Figure 1: Average Relative Humidity in Puttalam District (%), 2004-2006

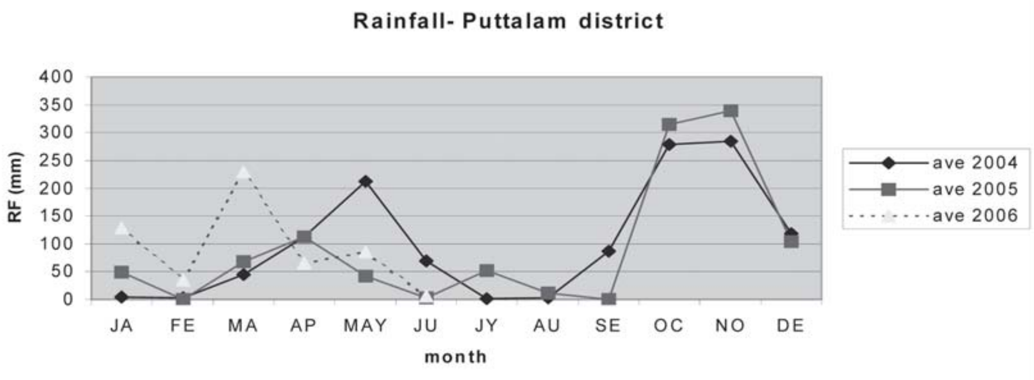


Figure 2: Average Rainfall Pattern in Puttalam District