Health Benefits from Urban Air Pollution Abatement in the Indian Subcontinent[1]

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Abstract:
This paper provides estimates of household health production model for the urban areas of Delhi and Kolkata that measure the benefits from reducing urban air pollution. A system of simultaneous equations comprising of health production function, demand for mitigating activities, and the demand for averting activities is estimated using 3SLS and GMM methods of estimation. The primary data about the health status and socioeconomic characteristics of households were collected for a sample of 1250 households from each city. An estimate of the marginal willingness to pay function and welfare gains for a representative household for reducing air pollution to the safe level is obtained for each city. The estimate of annual benefits to all the households in each city is made by extrapolation to the total urban population. This estimate is found to be Rs.4896.6 million for Delhi and Rs.2999.7 million for Kolkata.

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I. Introduction

Valuation of environmental quality improvements is needed for the evaluation of environmental policy changes, and the estimation of an environmentally corrected net national product. There are now a number of empirical studies estimating the benefits from the improved urban ecosystems: air quality, water supply and sanitation and tree cover in the developed countries. Given that there are not many similar studies available in the developing country context, environmental policy changes in the developing countries are evaluated using a benefit transfer method, which is a method of using the models estimated for the developed countries in order to make predictions about the benefits from the policy changes. The benefit transfer method may result in the under or over estimation of benefits from environmental policy changes because the behavioral responses of households in the developed countries could be different from those in developing countries for a given environmental policy change. This difference in the behavioral responses could be attributed to differences in socioeconomic characteristics and other attributes of households. It is therefore important to undertake a number of studies to estimate household production models using the developing country data to obtain accurate estimates of the benefits from environmental quality changes in these countries. This paper attempts to make a contribution in this direction.

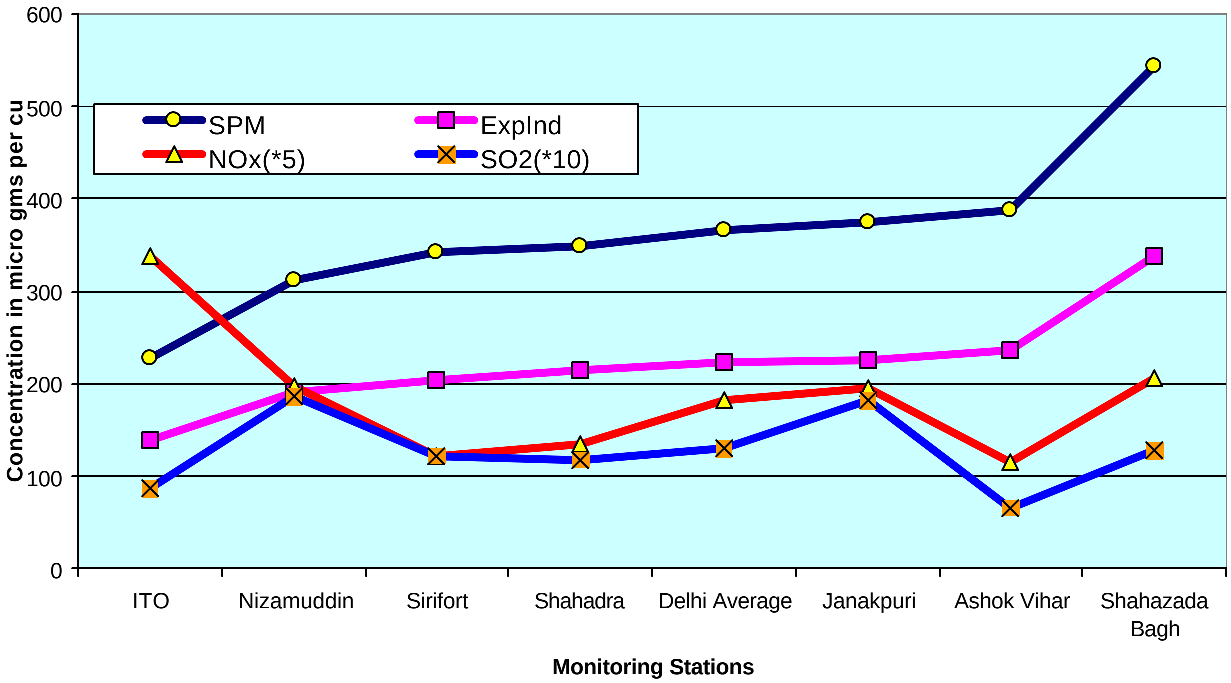
One could identify three stages in a comprehensive method of valuation of environmental changes (Freeman, 1993). In the first stage, a bio-physical relationship between the environmental policy instrument and the environmental quality has to be established. The policy instruments considered could be the formal regulation by government using command and controls, pollution taxes, and marketable permits; the informal regulation taking place by people’s participation and the market management. Market management may result in a negative change in environment while the other instruments are designed to bring about positive changes. In the second stage, a relationship between the environmental quality changes and the supply of environmental services like health, recreation, waste disposal, bio-diversity, climatic changes, and the sustainable livelihood for the poor has to be found. In the third stage, a monetary valuation of environmental services has to be attempted. Thus the measurement of environmental values requires an inter-disciplinary approach. In the first two stages it is the job of environmental scientists, engineers and ecologists to identify and estimate the relationship between policy changes and the environmental quality and the relationship between the environmental quality changes and further the environmental services. The monetary valuation in the third stage has to be done by the economists. There could be a role played by social scientists in the first two stages also if the behavioral responses of polluters (in controlling pollution) and the users of environment (in minimizing damages from pollution) to the environmental policy changes are taken into account.

The general approach of the valuation described above is common to various methods of valuation developed in the literature. These methods are classified as physical linkage methods and behavioral linkage methods. In the physical linkage methods, the dose response functions described in the first two stages of valuation are estimated and the monetary valuation of changes in the environmental services is made. For example, in the case of the effect of environmental changes on human health (morbidity and mortality effects), the monetary valuation is made using measures like the value of the statistical life, and the disability adjusted life years. In the case of behavioral methods, the responses of various economic agents to the environmental policy changes are taken into account. For example, in stage one the effect of policy change on the environmental quality depends on the behavioral response of polluters to the policy change. In the second stage, the effect of environmental quality changes on the environmental services depends on the behavioral responses of the users of those services. The health effects of air or water pollution depend upon the mitigating and averting activities of people to minimize health damages. Finally, the monetary valuation of environmental services depends on the people's perception of environmental values.

Various methods to measure benefits from environmental resources differ in their data requirements and the assumptions about economic agents and physical environments. The physical linkage methods assume that there is some sort of technological relationship between the environmental good and the user. The technological relationship can be either of an engineering or biological type. These methods are also called damage function or dose response function approaches meant for measuring the effects of deterioration of air or water quality using market prices. The behavioral linkage methods on the other hand are based on the behavioral linkages between a change in the supply of an environmental good and its effects. In these methods, the measurement of damages or benefits from a change in the supply of the environmental good depends on the behavioral responses of users in the observed or hypothetical situations. The behavioral linkage methods are classified as observed behavioral methods and as hypothetical behavioral methods. In the case of observed behavioral methods, the measurement of benefits or damages from a change in the supply of environmental good is made by making use of information related to the behavioral responses of users either in a simulated market for the environmental good or in the markets for private goods the demand for which depends upon the demand for the environmental good. In the case of hypothetical methods, individual values of the environmental good are elicited in hypothetical market-like scenarios created through survey methods. The observed behavioral methods are the household production function models and the hedonic prices methods while the hypothetical behavioral methods are the contingent valuation methods. In this paper, the household health production function model is used to estimate the benefits from the control of urban air pollution in Delhi, and Kolkata in the Indian subcontinent.

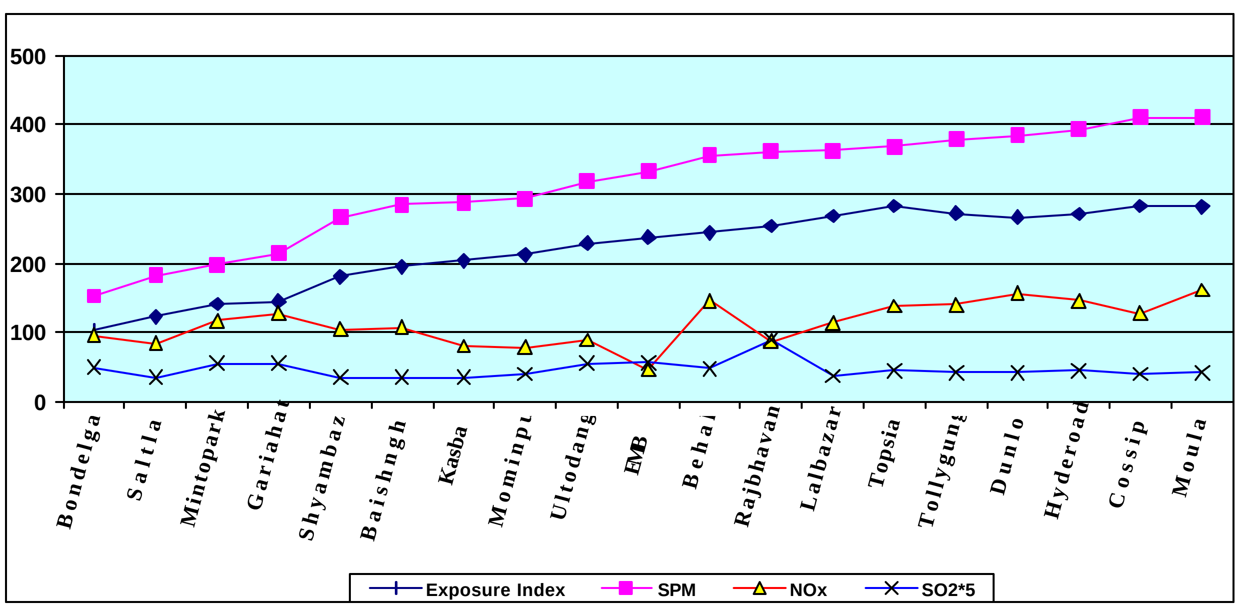
The household health production function model consisting of a system of three simultaneous equations called health production function, demand function for mitigating activities and demand function for averting activities is estimated to measure the benefits of reducing air pollution from the current to a safe level in the cities of Delhi and Kolkata in India. The pollution levels especially that of Suspended Particulate Matter (SPM) are much higher than the Minimum National Standards (MINAS) or the WHO standards in these two cities. Figures 1 and 2 explain the pollution levels recorded in 7 monitoring stations in Delhi and 19 monitoring stations in Kolkata. Pollution concentrations of SPM, SO_2 and NO_x reported in these figures are six monthly average concentrations during October-March, 2001-2002.

Fig. 1: Average concentrations of SPM, NOx, SO2 and the Exposure Index for the 7 monitoring stations in Delhi for the period October 2001 to March 2002.



Note: NOx and SO2 are given in multiples of 5 and 10 respectively for bringing uniformity in scale.

Fig. 2: Average concentrations of SPM, NOx, SO2 and the Exposure Index for the 19 monitoring stations in Kolkata for the period October 2001 to March 2002.



Source: Figure 1: CPCB, Delhi; Figure 2: WBPCB, Kolkata.

II. Methodology

The health production function model was first developed by Grossman (1972) and used by Cropper (1981) by using pollution as one of the inputs. Gerking and Stanley (1986) and Harrington and Portney (1987) have used this model to examine explicitly the relationships among willingness to pay for reduction in pollution, reduction in cost of illness, and changes in defensive expenditures. The most recent empirical studies of the household health production models differ with respect to the way in which the household health production function is specified and whether pollution provides direct utility to the household or not apart from providing indirect utility to the household through the health production function. There are models considering only pollution and averting activities as inputs in the household health production function (Alberini and Krupnick, 2000), and also more general models considering mitigation activities along with averting activities and pollution as inputs (Alberini and Krupnick, 1998). Some other studies take health capital as a variable in the health production function (Gerking and Stanely, 1986; Dickie and Gerking, 1990; Bresnahan et al. 1997).

Consider a more general model in which environmental quality Q, and mitigating activity M, aversion activity A, stock of health capital K, and stock of social capital S, like education level of a household are inputs of the health production function H.

$$H = H(Q,M,A,K,S), \qquad (1)$$

where H represents number of sick days.

Pollution affects individual utility indirectly through the health production function and directly by affecting the outdoor recreation and other amenity services. The utility function of the household is defined as

$$U(Y,H,Q, L,I), \qquad (2)$$

where Y is a private good other than M and A consumed by the household and L and I are leisure and income. The private good Y is taken as a numeraire. The household's budget constraint is given as

$$I = I^* + w(T-L-H) = Y + P_m M + P_a A \qquad (3)$$

Given the environmental quality level Q, the health capital K, human resource capital S, income I, and prices w, P_m, and P_a, the individual maximizes (2) with respect to Y, M, A, and L given the budget constraint.

Solution to this problem yields the demand function for mitigating activities and averting activities by the household.

$$\text{Max } G = U(Y,H,Q,L,I) + \lambda[I^* + w(T-L-H) - Y - P_m M - P_a A] \quad (4)$$

The first order conditions are given as

$$U_y = \lambda \quad (5a)$$

$$U_L = \lambda w \quad (5b)$$

$$U_H H_M = \lambda P_m + \lambda w H_M \quad (5c)$$

$$U_H H_A = \lambda P_a + \lambda w H_A \quad (5d)$$

From 5a and 5b one gets

$$\lambda P_m / H_M = U_H - \lambda w = \lambda P_a / H_A . \quad (6)$$

The indirect utility function V is given as

$$V(Q, P_m, P_a, K,S,I) \quad (7)$$

By taking the total differential of this function and equating it to zero, one gets

$$-V_Q / V_I = -V_Q / \lambda = dI/dQ \quad (8)$$

Also,

$$V_Q = U_Q + U_H .H_Q - \lambda w H_Q \quad (9)$$

$$= U_Q + (U_H - \lambda w) H_Q$$

By substituting (9) in (8) one gets

$$dI/dQ = - V_Q /\lambda = -(U_Q /\lambda + P_m H_Q / H_M) \quad (10)$$

$$= -(U_Q /\lambda + P_a H_Q / H_A) \quad (11)$$

By totally differentiating the household production function and equating it to zero one gets

$$H_M dM + H_A dA + H_Q dQ = 0 \quad (12)$$

For A at optimum, $-H_Q/ H_M = dM/dQ$ or for M at optimum, $-H_Q/ H_A = dA/dQ$.

In equations (10) and (11), the marginal willingness to pay (MWP) of an individual for the improved environmental quality or in a reduction in pollution (dI/dQ) is a sum of direct utility gains and indirect benefits from the improved health status through reductions in expenditures either on averting activities or on mitigating activities. The direct utility gains could be from the out door recreational or amenity services from the reduction in air or water pollution that are not captured through the health production function. The marginal willingness to pay for the gains in health benefits could be expressed in terms of marginal rate of technical substitution (MRTS) between pollution and any other input in the health production function since the values of marginal products of all inputs are equal at optimum. The estimation of MWP using the equations (10) and (11) requires an estimation of the health production function and the evaluation of MRTS at the current levels of input use and prices and the estimation of direct MWP for the amenity benefits from the reduction in pollution. The estimation of direct benefits requires the use of direct hypothetical observed methods of valuation like the contingent valuation method. Therefore as already observed in the literature (Bartik, 1988), the household health production model underestimates the benefits from the environmental improvement because it does not capture the direct utility benefits to the individual.

The equations (10) and (11) are expressions for the MWP of an individual at optimum and depend upon the values of M and A at the optimum. However, the actual data obtained from individuals through surveys give us the data about the observed values of M and A that may not be the optimum values. Therefore, it is useful to consider an alternative expression that shows the relationship between the observed M and A and the marginal willingness to pay. There are two steps in deriving this expression. The first step is to obtain the demand functions for M and A.

$$M = M(w, P_M, P_A, H, A, Q, I, K, S) \quad (13)$$

$$A = A(w, P_M, P_A, H, M, Q, I, K, S) \quad (14)$$

These functions express the optimum quantities of M and A as functions of prices, environmental quality, income, health capital and human capital.

The second step is to take the total derivative of the health production function

$$dH/dQ = \delta H/\delta M.\ \delta M/\delta Q + \delta H/\delta A.\ \delta A/\delta Q + \delta H/\delta Q \quad (15)$$

This gives the effect of change in pollution on health after taking into account the optimal adjustments of M and A to the change in pollution. Thus equation 15 could be written as

$$\delta H/\delta Q = dH/dQ - \delta H/\delta M.\ \delta M/\delta Q - \delta H/\delta A.\ \delta A/\delta Q$$

Multiplying this expression by the optimal condition in (10) or (11), one could write

$$P_M \frac{\delta H/\delta Q}{\delta H/\delta M} = (U_H - \lambda w)\, dH/dQ - (U_H - \lambda w)\, \delta H/\delta M.\ \delta M/\delta Q - (U_H - \lambda w)\ \delta H/\delta A \delta A/\delta Q \quad (16)$$

After rearranging

$$dI/dQ = w\, dH/dQ + P_M\, \delta M/\delta Q + P_A\, \delta A/\delta Q + \frac{\delta u/\delta H}{\lambda} dH/dQ \qquad (17)$$

This expression shows that MWP for health benefits from reduction in pollution is the sum of observable reductions in the cost of illness, cost of mitigating and averting activities and the monetary equivalent of disutility of illness. The estimation MWP (dI/dQ) using this equation requires the estimation of health production function (1) and the demand functions (13; 14) for M and A. These have to be estimated as a system of simultaneous equations.

III. Data and Model Formulation

Data about the health status and socio-economic characteristics of households are obtained through the household surveys of Delhi and Kolkata. A sample of 1250 households in each city was surveyed. The Delhi survey was conducted during May-June while the Kolkata survey was done during the month of July in the year 2002. There are 7 monitoring stations in Delhi and 19 monitoring stations in Kolkata providing regular monthly data on the air pollution concentrations of SPM, NO_x, and SO_2. The sample of 1250 households in each city was distributed among the areas representing 7 monitoring stations in Delhi and 19 monitoring stations in Kolkata. A sub-sample of households allotted to a monitoring station is drawn from the house locations within the a kilometer radius of the monitoring station.

Data about the health status of the household were collected for a recall period of six months. Information of the health history, and the health stock of the household are obtained. The detailed data collected consists of the number of days of sickness, number of visits to the doctor, expenditure on medicines, doctor fees and diagnostic tests, number of days stayed indoors to avoid exposure to pollution, extra miles traveled in a day to avoid polluted areas in the city and other averting activities. Data was also collected about defensive activities such as use of air conditioner, cooking gas, and the exhaust fan in the kitchen to reduce indoor air pollution. Information was also collected about the chronic diseases in the family, habits of family members affecting their health, and the general awareness of the household about diseases attributed to air pollution.

Information about the demographic characteristics of households such as family size, age and sex composition of the family, and the education level of family members, and the occupation of the respondent was collected. Data about the gross annual income of family, family monthly average household expenditure and the household inventory were obtained through the household survey.

The household health production model described in Section II requires the estimation of a simultaneous equations model consisting of three equations: household health production function, household demand functions for mitigating activities; and for averting activities. The variables used in the estimation of model consist of three endogenous variables and a number of exogenous variables. The construction of variables is described as follows:

Endogenous Variables

Health status of the Household: (Y1) The number of days of sickness in each household over a period of 6 months is used as a measure of the health status and it enters as the dependent variable (Y_1) in equation (18), the first equation of the model. This information was obtained by directly asking the respondent about the total days of sickness for each adult and child member in that household over the last six months.

Doctor Visits: (Y4) An alternative measure of the health status of each household is captured by the total number of doctor visits (Y_4) made by each member of the household over a period of 6 months. The number of visits by each member is added up to arrive at the figure for the household. This information is collected from the respondent.

Mitigating Activity: (Y2) The medical expense of the household in the last 6 months, which figures as the dependent variable (Y_2) in equation (19), the second equation of the model, was used to denote the total expenses on mitigating activities and it includes expenditure on medicines, doctor fees and diagnostic tests. The reported figure for each household is a cumulative one including expenses of all the adult and child members. This information was obtained by directly asking the respondent.

Averting Activities: (Y3) An ordered variable in the range of 0 to 4 is used to measure the averting activity for each household, which figures as dependent variable (Y_3) in equation (20). These activities includes the number of days stayed indoor to avoid exposure to pollution, extra miles traveled in a day to avoid polluted areas in the city, using a gas mask while traveling and any other household specific averting activities. Extra miles traveled was captured both as a continuous variable i.e. in miles and as a discrete binomial variable. Undertaking all activities scored 4 and the absence of all was marked at 0. This was also based on the input from the respondent.

Exogenous Variables

Household Air Pollution Exposure Index: (X1) The Exposure Index (X_1) is constructed out of the information on the concentration of SPM in a locality and household specific information on the age and gender composition of the household. Assuming different hours of exposure to local air pollution for household members belonging to different age groups (18 hours for children, 15 hours for adult females and 12 hours for the adult male members), a weighted index of exposure was constructed thereby converting the area specific information on SPM concentration into a household specific one. The other two important air pollutants SO_2 and NO_x are below the safe or MINAS standard levels in Delhi. In Kolkata the SPM and NO_x levels are above the MINAS standards while SO_2 levels are below the MINAS standard. Therefore, a pollution exposure index NO_x (X_9) is constructed on the similar lines.

Chronic Disease Index: (X2) The index for Chronic Diseases (X_2), which measures the health capital of the household, is an ordered variable of the range 0 to 8. Out of the 8 chronic diseases considered namely Diabetes, high BP, Glaucoma, T.B., Cancer, Asthma, Heart Disease or anything specific, a household that has none of these scores 0 and the one with all is pegged at 8. Further, a system of weighting using the inverse of the frequency of occurrence of any chronic disease within the sample of households with respect to the others is used to highlight the most infrequent but highly expensive diseases like Cancer as against high BP or Diabetes. This also helps in controlling for the higher expenses in a household suffering from critical chronic diseases in an estimation of the household health production function. Information is gathered from the respondent.

Family Size: (X3) Family size (X_3) operates as a control variable for higher days of sickness or medical expenses in a large sized household. Information is collected from the respondent.

Index for Habits: (X4) The index for habits (X_4) is constructed by considering the presence of bad habits like smoking, drinking, not going for morning or evening walks and not exercising in the household. Information on each member of the household is collected separately and thereafter cumulated and adjusted for family size. Again a system of weighting is used with an inverse of the frequency of any habit being used by the sample households as weights to arrive at the constructed index of bad habits used in the estimation. It functions as a control variable in an estimation of the household health production. The basic information for this is collected from the respondent.

Awareness for Air Pollution Borne Diseases: (X5) The awareness index for air borne diseases (X_5) is constructed by taking the proportion of the diseases known to the respondent (head of the family) to the total of 18 diseases that are clinically proven to be related to air pollution.

Ratio of Females to Size of Household: (X6) The ratio of female members (X_6) to he total was considered to surface the effect of gender on the medical expenses incurred by a household. With the growing emphasis in the literature on "gender and say" this variable does not seem out of place as a control variable.

Gross Annual Household Income: (X7) The income variable (X_7) controls for capacity to spend and the actual health expenses among the households. It is based on the gross annual family income of the household. In the absence of any concrete figures for actual incomes it was necessary to offer certain income brackets to the respondent to choose from. But in a large number of households the actual figures could be elicited.

Index for Indoor Pollution: (X8) The index for indoor pollution (X_8) controls for cleanliness of the indoor air. This is a crucial control variable that appears in the equation for averting activities. The variable controls for the fuel used in the house, not using heater in winter, having exhaust fans and chimneys in the kitchen and use of air conditioners at home. This finds place in the Averting Activity equation to control for the quality of indoor air, which is expected to have a positive effect on the number of averting activities that a person undertakes when she leaves her house. Presence of all good controls throws up the value of 4 for the household and it can be 0 in the worst case.

Exposure to NOx Index: (X9) A pollution exposure index for NO_X (X_9) is also constructed on lines similar to exposure index for the SPM (X_1)

City Dummy: **(X10)** A dummy variable (X_{10}) taking the value 1 for households belonging to Delhi and value 0 for the households belonging to Kolkata is constructed.

Descriptive statistics of the endogenous as well as exogenous variables are provided in Tables 1, 2 and 3 for Delhi, Kolkata and for pooled data for Delhi and Kolkata, respectively.

Table 1: Descriptive Statistics for Variables Used in Health Production Function Model for Urban Households in Delhi

Descriptive Statistics	Days of Sickness (Y_1)	Medical Expenses in Rs. (Y_2)	Averting Activities (Y_3)	Doctor Visits (Y_4)
Mean	13.88880	1341.950	1.250211	3.510110
Std. Dev.	32.43656	2662.611	0.961610	6.563825
Observations	1187	1187	1187	1187

Descriptive Statistics	Exposure Index (X_1)	Index of Chronic Diseases (X_2)	Family Size (X_3)	Habit Index (X_4)
Mean	224.0285	76.24762	5.466723	7.640171
Std. Dev.	57.47378	23.83485	2.758925	6.692175
Observations	1187	1187	1187	1187

Descriptive Statistics	Index of awareness about air pollution (X_5)	Female ratio (X_6)	Annual household Income in Rs. (X_7)	Indoor Pollution Index (X_8)
Mean	0.550872	0.449254	179565.3	2.652906
Std. Dev.	0.218208	0.154985	127156.2	0.823863
Observations	1187	1187	1187	1187

Table 2: Descriptive Statistics for Variables used in Health Production Function Model for Urban Households in Kolkata

Descriptive Statistics	Days of Sickness (Y_1)	Medical Expenses in Rs. (Y_2)	Averting Activities (Y_3)	Doctor Visits (Y_4)
Mean	10.18995	1700.00	0.548884	4.272132
Std. Dev.	16.20711	33135.43	0.766018	14.92723
Observations	1299	1299	1299	1299

Descriptive Statistics	Exposure Index for SPM (X_1)	Exposure Index for NO_x (X_9)	Index of Chronic Diseases (X_2)	Family Size (X_3)	Habit Index (X_4)
Mean	235.9697	83.47448	7.635950	4.600462	7.670635
Std. Dev.	76.96757	36.07114	19.18954	2.200931	5.059312
Observations	1299	1299	1299	1299	1299

Descriptive Statistics	Awareness about air pollution (X_5)	Female ratio (X_6)	Annual household Income in Rs. (X_7)	Indoor Pollution Index (X_8)
Mean	8.047729	0.470670	156803.6	1.465743
Std. Dev.	3.162648	0.177569	102261.3	0.842453
Observations	1299	1299	1299	1299

Table 3: Descriptive Statistics for Variables used in Health Production Function Model for Urban Households for the pooled data of Delhi and Kolkata

Descriptive Statistics	Days of Sickness (Y_1)	Medical Expenses in Rs. (Y_2)	Averting Activities (Y_3)	Doctor Visits (Y_4)
Mean	12.40601	1514.70	0.926279	4.000217
Std. Dev.	26.16156	21531.37	0.941561	12.12881
Observations	2486	2486	2486	2486

Descriptive Statistics	Exposure Index for SPM (X_1)	Exposure Index for NO_x (X_9)	Index of Chronic Diseases (X_2)	Family Size (X_3)	Habit Index (X_4)
Mean	222.2515	75.83224	43.19748	5.028187	7.845086
Std. Dev.	58.76189	25.05463	40.26247	2.511334	5.977933
Observations	2486	1299	2486	2486	2486

Descriptive Statistics	Awareness about air pollution (X_5)	Female ratio (X_6)	Annual household Income in Rs. (X_7)	Indoor Pollution Index (X_8)
Mean	4.144356	0.460149	168968.7	2.087598
Std. Dev.	4.311843	0.164355	116341.5	1.030196
Observations	2486	2486	2486	2486

Formulated Structural Model

The model used in the estimation is specified as follows:

$$\ln Y_{1i} = \alpha_1 + \beta_1 \ln X_{1i} + \beta_2 \ln X_{2i} + \beta_3 \ln X_{3i} + \beta_4 \ln X_{4i} + \beta_9 \ln X_{9i} + \beta_6 \ln Y_{2i} + \beta_7 \ln Y_{3i} + u_{1i} \quad (18)$$

$$\ln Y_{2i} = \alpha_2 + \beta_7 \ln X_{1i} + \beta_8 \ln X_{2i} + \beta_{10} \ln X_{5i} + \beta_{11} \ln X_{6i} + \beta_{12} \ln X_{7i} + \beta_{13} \ln X_9 + \beta_{14} \ln Y_{1i} + \beta_{15} \ln Y_{3i} + u_{2i} \quad (19)$$

$$\ln Y_{3i} = \alpha_3 + \beta_{16} \ln X_{1i} + \beta_{17} \ln X_{2i} + \beta_{18} \ln X_{5i} + \beta_{19} \ln X_{8i} + \beta_{20} \ln X_{9i} + \beta_{21} \ln Y_{1i} + \beta_{22} \ln Y_{2i} + u_{3i} \quad (20)$$

The equations (18), (19), and (20) constitute a simultaneous equation system with three endogenous variables and ten exogenous variables. Equation (18) represents the household health production function expressing the health status given in terms of number of sick days in a household as a function of mitigating expenditures, averting expenditures, exposure to pollution, and the health stock represented by the variables chronic diseases index, index of bad habits and the family size. In this model, the household decision variables determining the health status are mitigating and averting expenditures while the health stock and family size are control variables. Equations (19) and (20) represent the household demand functions for mitigating and averting activities. Variables common to both the demand functions are exposure to pollution, health status, health stock, household annual income, and index of awareness of air pollution related diseases. Variable specific to the demand function for mitigating activities is proportion of females in the family while the variable specific to the demand function for averting activities is index for indoor pollution.

Application of the Hausman test for exogeneity of Y_2 and Y_3 in the first structural relation pertaining to sick days reveals that the Null Hypothesis of exogeneity of Y_2 and Y_3 appearing as explanatory variables is rejected at the 14 % level of significance. Furthermore, in the testing of the exogeneity of individual variables namely Y_2 and Y_3, using a t-test, we find that Y_1 and Y_3 are strongly interconnected (at 5 percent level of significance), while Y_1 and Y_2 are feebly interconnected. Thus, the formulation of a simultaneous structural system became essential to obviate the problem of simultaneity between Y_1, Y_2 and Y_3.

It can be noted that the formulated structural system is overidentified. The model is estimated using 3SLS and the Generalized Methods of Moments (GMM). The model is estimated separately for Delhi, Kolkata and also for the pooled data of Delhi and Kolkata with a city specific dummy (X_{10}) in the structural equations.

IV. Parametric Estimates of the Household Health Production Model and Estimates of Welfare Gains from Air Pollution Reduction to Households

Parametric estimates of the structural equations (18), (19) and (20) using 3SLS estimational procedure for the survey data for Delhi, Kolkata, and for the pooled data of Delhi and Kolkata are provided in columns 3, 4, and 5 of Table 4. Table 5 provides corresponding estimates obtained using GMM.

Perusal of Table 4 reveals that five out of seven parameters in the health production function have turned out to be significant in the case of Delhi. The four significant parameters correspond to mitigating expenditures, averting expenditures, family chronic disease index, and family size which are significant at the 1 % level while the one that represents pollution or exposure to SPM is significant at 5 percent level. The coefficients of all the variables have expected signs in this equation. The demand function for mitigating expenditures has eight coefficients out of which two corresponding to the variables namely sick days, and averting expenditures, have turned out to be significant at the 1 % level with expected signs. Furthermore, the estimated coefficient corresponding to the variable characterizing chronic diseases is significant at the 5 % level but having opposite sign, while the coefficient representing the variable exposure to SPM is significant at the 10 % level with a required sign. The demand function for averting expenditures has seven parameters out of which two namely sick days and mitigating expenditures, have turned out to be significant at the 1 % level and are having required signs. The coefficient of chronic diseases index is significant at the 5 % level with the required sign while the coefficient of exposure to SPM is significant at the 10 % level with the required sign. Most of the coefficients of other variables are having required signs even though they are not significant. The estimated health production models for Kolkata and the pooled data of Kolkata and Delhi provide similar types of estimates for the relevant parameters that could be seen from the columns 3 and 4 of Table 4.

Table 4: Estimates of the Health Production Function Model using 3SLS

Locations:	Delhi	Kolkata	Pooled
Equation 1: Dependent Variable is Ln (Y_1)			
Log values of Variables (Expected signs)	Coefficients (t-statistics)	Coefficients (t-statistics)	Coefficients (t-statistics)
Constant	-1.184 (-1.1804)	-3.017** (-2.905)	-2.367*** (-3.465)
Y_2 (Med Expense) (+)	0.506*** (6.719)	0.286* (1.701)	0.328*** (5.660)
Y_3 (Avert Act) (-)	-2.127*** (-3.179)	-1.975** (-2.521)	-1.715*** (-3.920)
X_1 (Exposure SPM) (+)	0.452** (2.105)	0.269* (1.763)	0.414*** (4.002)
X_2 (Chronic) (+)	0.191*** (3.219)	-0.048 (-0.625)	0.019 (0.528)
X_3 (Family size) (+)	0.168*** (2.657)	0.0178 (0.179)	0.228*** (3.726)
X_4 (Bad Habits) (+)	0.011 (0.830)	0.065 (0.721)	0.032 (0.958)
X_9 (Exposure NO_x) (+)		0.484*** (3.515)	
$^{\$}X_{10}$ (City Dummy)			1.092*** (3.623)
Equation 2: Dependent Variable is Ln (Y_2)			
Constant	2.695 (1.074)	5.345*** (3.242)	3.806 (0.911)
Y_1 (Sick Days) (+)	1.433*** (3.452)	1.457*** (5.061)	2.211*** (3.296)
Y_3 (Avert Act) (+)	4.541*** (5.293)	3.309*** (3.783)	4.931*** (5.076)
X_1 (Exposure SPM) (+)	0.954* (1.943)	0.439* (1.788)	0.426 (0.780)
X_2 (Chronic) (+)	-0.348** (-2.386)	-0.176** (-2.388)	-0.053 (-0.324)
X_5 (Awareness) (-)	0.748 (1.159)	-0.022 (-0.195)	0.087 (0.365)
X_6 (Female prop) (-)	-0.144 (-1.126)	0.695 (1.540)	-2.900 (-1.014)
X_7 (Income) (+)	-0.008 (-0.116)	0.276*** (2.584)	-0.008 (-0.084)
X_9 (Exposure NO_x) (+)		0.777*** (2.989)	
$^{\$}X_{10}$ (City Dummy)			-3.324*** (-2.752)
Equation 3: dependent Variable is Ln(Y_3)			
Constant	-0.605 (-1.372)	-0.710 (0.237)	-0.953*** (2.945)
Y_1 (Sick Days) (-)	-0.205 (-2.378)	-0.327*** (-3.677)	-0.215*** (-3.346)
Y_2 (Med Expense) (+)	0.174*** (7.268)	0.043 (0.413)	0.153*** (4.505)
X_1 (Exposure SPM) (+)	0.204*** (2.721)	0.063 (0.865)	0.140*** (2.788)
X_2 (Chronic) (+)	0.065*** (2.645)	-0.445 (-1.121)	0.024* (1.653)
X_5 (Awareness) (+)	-0.013 (-0.095)	-0.011 (-0.428)	-0.026 (-0.505)
X_7 (Income) (+)	-0.006 (-0.307)	0.017 (0.377)	-0.009 (-0.476)
X_8 (Indoor Poll) (+)	0.064** (2.408)	0.072 (1.530)	0.083** (2.364)
X_9 (Exposure NO_x)		0.165** (2.442)	
$^{\$}X_{10}$ (City Dummy)			0.650*** (5.461)

Notes: *, **, and *** denote significance at 10, 5 & 1 % levels, respectively.
$^{\$}$ denotes variables used without Ln transformation.

Table 5: Estimates of the Health Production Function Model Using GMM.

Locations:	Delhi	Kolkata	Pooled
Equation 1: Dependent Variable is Ln (Y_1)			
Log values of Variables (Expected signs)	Coefficients (t-statistics)	Coefficients (t-statistics)	Coefficients (t-statistics)
Constant	-1.287 (-1.343)	-3.389** (-2.302)	-2.499*** (-3.543)
Y_2 (Med Expense) (+)	0.517*** (6.389)	0.281* (1.645)	0.332*** (5.387)
Y_3 (Avert Act) (-)	-2.239*** (-3.069)	-1.757** (-2.197)	-1.657*** (-3.830)
X_1 (Exposure SPM) (+)	0.473** (2.279)	0.358** (2.014)	0.429*** (4.137)
X_2 (Chronic) (+)	0.189*** (3.664)	-0.039 (-0.522)	0.012 (0.337)
X_3 (Family size) (+)	0.185*** (2.729)	0.022 (0.222)	0.247*** (3.861)
X_4 (Bad Habits) (+)	0.015 (1.093)	0.072 (0.786)	0.041 (1.202)
X_9 (Exposure NO_x) (+)		0.458*** (3.334)	
$^{\$}X_{10}$ (City Dummy)			1.047*** (3.373)
Equation 2: Dependent Variable is Ln (Y_2)			
Constant	2.436 (1.000)	5.563*** (3.288)	4.122 (0.973)
Y_1 (Sick Days) (+)	1.375*** (3.217)	1.367*** (4.473)	2.018*** (2.981)
Y_3 (Avert Act) (+)	4.613*** (5.226)	2.679*** (3.272)	4.795*** (4.781)
X_1 (Exposure SPM) (+)	0.921* (1.942)	0.495** (-1.956)	0.433 (0.786)
X_2 (Chronic) (+)	-0.327*** (2.619)	-0.186** (-2.413)	-0.056 (-0.348)
X_5 (Awareness) (-)	0.729 (0.261)	0.031 (0.789)	0.064 (0.269)
X_6 (Female prop) (-)	-0.152 (-1.125)	0.675 (1.476)	-2.644 (-0.919)
X_7 (Income) (+)	0.009 (0.119)	0.261*** (2.552)	0.003 (0.028)
X_9 (Exposure NO_x) (+)		0.679*** (2.709)	
$^{\$}X_{10}$ (City Dummy)			-3.403*** (-2.791)
Equation 3: dependent Variable is Ln(Y_3)			
Constant	-0.522 (-1.167)	-0.781 (-1.333)	-0.903*** (-2.731)
Y_1 (Sick Days) (-)	-0.201** (-2.238)	-0.343*** (-4.014)	-0.1997*** (-3.147)
Y_2 (Med Expense) (+)	0.174*** (7.182)	0.030 (0.298)	0.149*** (4.421)
X_1 (Exposure SPM) (+)	0.192*** (2.553)	0.090 (1.251)	0.138*** (2.751)
X_2 (Chronic) (+)	0.062*** (2.756)	-0.049 (-1.236)	0.022 (1.583)
X_5 (Awareness) (+)	-0.002 (-0.012)	-0.007 (-0.296)	-0.027 (-0.512)
X_7 (Income) (+)	-0.009 (-0.495)	0.016 (0.358)	-0.014 (-0.729)
X_8 (Indoor Poll) (+)	0.066** (2.457)	0.089* (1.911)	0.099*** (2.835)
X_9 (Exposure NO_x)		0.172*** (2.592)	
$^{\$}X_{10}$ (City Dummy)			0.638*** (5.300)

Notes: *, **, and *** denotes significance at 10, 5 & 1 % levels.
$ denotes variables used without Ln transformation.

It may be of interest to mention that parametric estimates derived by he 3SLS method of estimating the structural relations are in close correspondence with the GMM estimates provided in Table 5 in terms of magnitudes as well as expected signs, which depicts the stability of the coefficients by the two alternate estimational procedures of the model. Since all the structural equations are overidentified the J-Statistic obtained from the GMM estimates is used to test the Null hypothesis that the over identifying restrictions are satisfied. The J-statistic times the number of observation follows χ^2 distribution asymptotically with degrees of freedom equal to the number of overidentified restrictions. For each of the equations the Null Hypothesis is not rejected at the 1% level of significance.

The welfare gains are estimated using the parametric estimates of the 3SLS. Given the estimates of the household health production model for Delhi, Kolkata, and the pooled data of Delhi and Kolkata, the household marginal willingness to pay (MWP) for reduction of one microgram of SPM/m^3 could be estimated using the equation (17) in Section II as

$$\textbf{MWP} = \frac{\partial(Sickdays)}{\partial Exposure(SPM)}W + \frac{\partial(Medical\_Expenses)}{\partial Exposure(SPM)} + \frac{\partial(Averting\_Expenses)}{\partial Exposure(SPM)} \qquad \textbf{(21)}$$

Equation (21) could be written respectively for Delhi, Kolkata and pooled data as

$$\textbf{MWPD} = \frac{0.542(Sickdays)}{Exposure(SPM)}W + \frac{0.954(Medical\_Expenses)}{Exposure(SPM)} + \frac{0.204(Averting\_Expenses)}{Exposure(SPM)} \qquad \textbf{(22a)}$$

$$\textbf{MWPK} = \frac{0.269(Sickdays)}{Exposure(SPM)}W + \frac{0.439(Medical\_Expenses)}{Exposure(SPM)} + \frac{0.063(Averting\_Expenses)}{Exposure(SPM)} \qquad \textbf{(22b)}$$

$$\textbf{MWPP} = \frac{0.414(Sickdays)}{Exposure(SPM)}W + \frac{0.426(Medical\_Expenses)}{Exposure(SPM)} + \frac{0.140(Averting\_Expenses)}{Exposure(SPM)} \qquad \textbf{(22c)}$$

Tables 1, 2 and 3 provide the descriptive statistics of sick days in the family, medical expenses, averting activity, and the family exposure to SPM for the recall period of six months. While the medical expenses are already measured in monetary terms, the monetary values of sick days and averting activity have to be estimated. Using the data for a sample of households surveyed in each city, an estimate of per day income (W), earned by an adult working member of the family is made. Using information from the data of population census in India, it is assumed that 70 % of urban household members are working members.

Assuming on average the family members suffered six days of sickness during the recall period of six months, an estimate of income loss to the household due to sick days is made.

The averting activity is measured as an ordered variable taking the value in the range of 0 to 4. In the household survey, information is collected about whether any members of the family are involved in staying indoors to avoid exposure to pollution, avoiding traveling through polluted areas, using masks while going out and any other activity. It is found that staying indoors, and avoiding traveling through polluted areas result in significant monetary losses to the households. Data for the pooled sample of Delhi and Kolkata show that about 27 % of households reported some members from the family staying indoors while 46 % report saying that some members of family indulge in extra travel daily to avoid polluted areas. The cost to the family of staying indoors is estimated given an estimate of days stayed indoors during the recall period of six months and an estimate of per day income earned by the adult working member of the family. Income loss to the family due to extra kilometers traveled every day is estimated given the estimate of extra kilometers traveled and an estimate of user cost of one passenger kilometer travel (fuel cost plus capital cost). Table A1 in appendix provides the details of calculations of household MWP for reduction of SPM.

Table 6: Annualized Monetary Value of Gains

Annualized monetary value of gains to a typical household due to reduction in exposure to pollution by 1 ì gms/m^3		**Annualized monetary value of gains to a typical household by reducing exposure from the current average to the safe level, corresponding to 200 ì gms/m^3 SPM**
Locations (1)	Total gains (2)	Total gains (3)
Delhi	Rs.19.86	Rs.2085.46
Kolkata	Rs.8.13	Rs.950.21
Pooled	Rs.10.22	Rs.1466.90

Column 2 of Table 6 provides the estimates of annual marginal benefits or MWP for a representative household in Delhi, Kolkata and the urban areas of Delhi and Kolkata together by reducing one microgram of concentration in SPM/m^3 from its current level. The estimate of MWP for a representative household from Delhi and Kolkata is respectively Rs. 19.86 and Rs. 8.13. Column 3 provides estimates of annual benefits to a representative household by reducing the SPM concentration from the current level to the MINAS standard of 200ì gms/m^3 SPM. The estimate of annual welfare gain to a representative household from Delhi and Kolkata is respectively, Rs. 2085.46 and Rs. 950.21.

V. Welfare Gains from Air Pollution Reduction and Environmental and Economic Accounting in India

Conservation of urban ecosystems consisting of air, water and tree cover forms an integral part of urban planning. The cost of conserving urban ecosystems or the cost of ecologically sustainable urbanization should constitute an integral part of the budget for urban development. Alternatively, ecologically unsustainable urbanization affects the ecological functions of land, water, air and forests resulting in damages to the society.

The estimation of environmentally corrected net national product (ENNP) requires the accounting for either cost of environmental sustainable urban development or for the damages from unsustainable development. Health damages from urban air pollution estimated in this paper forms part of damages from the environmentally unsustainable urban development in India.

Table 7: Estimated Total Gains to the Entire Urban Households from Reduction of Pollution Concentration of SPM to Safe level

Annualized monetary gains to the entire Urban Population due to reduction of Exposures to SPM from the Current average to the Safe level, corresponding to 200 ì gms/m^3 SPM	
Delhi	**Rs.4896.6 millions**
Kolkata	**Rs.2999.7 millions**
Pooled	**Rs.7896.3 millions**

Estimation of benefits from reducing air pollution to the entire urban population in each city could be made given the estimate of benefits for a representative household and an estimate of the number of households in the city. The estimated number of households based on Census 2001 population data is 2347942 for Delhi and 3157452 for Kolkata. Table-6 provides the estimates of health benefits from reducing air pollution or damages from air pollution to the citizens of Delhi and Kolkata. The estimated benefits turn out to be

Rs.4896.6 million for Delhi and Rs. 2999.7 million for Kolkata. These estimates combined with similar type of estimates for other urban areas in India could provide an estimate of damages from environmentally unsustainable urban development in India in the context of urban air pollution.

As it is evident from the model of household health production function described for estimation in Section IV, the benefit estimates provided above represent only the benefits from the decreased morbidity from the reduction of air pollution. There could be significant benefits to the households from the reduced mortality that are not measured in this paper. Also, there could be direct utility benefits to the households from the reduced air pollution as described in the methodology of household health production function presented in Section III. After accounting for all these benefits, the benefit estimates from the urban air pollution reduction could be much higher than those reported above. Also, the other behavioral methods of valuation like hedonic property values or contingent valuation are supposed to capture all these benefits.[1]

VI. Conclusion

There could be a trade off between urbanization and the sustainability of urban ecosystems: air, water and land. The environmentally unsustainable urban development might result in a demand for ecological services exceeding the carrying capacity of urban ecosystems leading to their degradation. The air and water pollution and land degradation contribute to health damages, and direct utility losses to households in an urban area. These losses to households could be avoided by environmentally sustainable urban planning at certain extra costs that could be still less than the losses avoided.

Scientifically determined environmental standards, for example, the MINAS standards for air and water pollution in India or WHO standards, are supposed to be determined by the carrying or natural regenerative capacity of environmental media. Violation of these standards in urban development as it is found in this paper could result in health and other

[1] See Murty, Gulati and Banerjee (2003) for the estimates of benefits from reducing air pollution in Delhi and Kolkata using the hedonic property value model.

damages to the households. Health damages are in the form of morbidity and mortality effects on urban citizens. The annual damages from the morbidity effects of current levels of air pollution in the cities of Delhi and Kolkata are found to be of the order of Rs. 4896.6 million and Rs. 2999.7 million.

The total damages to households in these two cities could be much higher than the damages from morbidity effects estimated in this. It is possible to estimate the total damages either by using the hedonic property prices method or the contingent valuation method.

Benefit transfer method, a method of using the parameters of estimated models of environmental values in the developed countries to make estimates of environmental values in the developing countries, is used to make estimates of damages from air and water pollution, and forest degradation in the developing countries. Such methods even though they provide over or underestimates of damages or benefits are justified on the grounds that the data are not available to estimate environmental values in the developing countries. An example is a case of using the parameters of the household health production model estimated for Los Angelus in the USA to predict the damages from urban air pollution in Delhi, Kolkata or any other metropolitan city in India. The same logic of benefits transfer method could be used within the parameters of household health production function model estimated using the pooled data of Delhi and Kolkata to predict the health damages from air pollution for other metropolitan areas of Mumbai, Chennai, Bangalore and Hyderabad in India. The estimate of health damages from air pollution in all the metropolitan cities of India, if it could be obtained, might be taken as part of the cost of environmentally unsustainable urban development in India.

APPENDIX-A

Table A1: Marginal Willingness to pay (MWP) for reduction in SPM from the Current Average to the Safe level of 200 ì g/m^3

Expression for MWP = $\frac{\partial(Sickdays)}{\partial Exposure(SPM)} + \frac{\partial(MedicalExpenses)}{\partial Exposure(SPM)} + \frac{\partial(AvertingActivity)}{\partial Exposure(SPM)}$

Locations	$\frac{\partial(Sickdays)}{\partial Exposure(SPM)}$	$\frac{\partial(MedExp)}{\partial Exposure(SPM)}$	$\frac{\partial(AvertAct)}{\partial Exposure(SPM)}$	**Mean values**						
				In last 6 months				*AINC	Family Size	$Urban Population
				Sick Day	Med Exp	Averting Activity	Exposure (SPM)			
Delhi	0.028	5.715	0.001	13.88	Rs.1341.95	1.25	224.02	Rs.141.6	5.46	12819761
Kolkata	0.012	3.163	0.0001	10.18	Rs.1700.00	0.55	235.96	Rs.106.9	4.56	14397983
Pooled	0.022	2.802	0.0006	12.41	Rs.1514.7	0.926	230.26	Rs.125.6	5.01	27217744

Locations	**Proportion of sample undertaking the following Averting Act**				**#Extra Km traveled per day**	**Annualized monetary value of gains to a typical household due reduction in exposure to Pollution by 1 ì gms/m^3**			
	@Staying indoor	Using Mask	Avoiding Busy Road	Any Other		Sick Days	Medical Expenses	Averting Activities	Total gains
Delhi	0.34	0.15	0.61	0.37	3.3	Rs.5.55	Rs.11.43	Rs.2.88	Rs.19.86
Kolkata	0.20	0.04	0.31	0.15	0.73	Rs.1.74	Rs.6.33	Re.0.06	Rs.8.13
Pooled	0.27	0.09	0.46	0.25	1.96	Rs.3.93	Rs.5.60	Re.0.69	Rs.10.22

Locations	**Annualized monetary value of gains to a typical household by reducing exposure from the current average to the safe level, corresponding to 200 ì gms/m^3 SPM**	**Annualized monetary gains to the entire Urban Population due to reduction of Exposures to SPM from the Current average to the Safe level, corresponding to 200 ì gms/m^3 SPM**
Delhi	Rs.2085.46	**Rs.4896.6 millions**
Kolkata	Rs.950.21	**Rs.2999.7 millions**
Total	Rs.1466.90	**Rs.7896.3 millions**

Notes: @ Assuming 6 days to staying indoor by a household in 6 months.

$ Census 2001.

Assuming total cost of Rs.4 /- per Km. (Fuel cost plus annualized value of Capital costs) and 22 as the number of working days in a month.

* AINC stands for average per capita per day income of a typical household corrected for number of working adults in the house at 0.7 of the family

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