Measuring Benefits from Reduced Air Pollution in the Cities of Delhi and Kolkata in India Using Hedonic Property Prices Model

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Abstract:
This paper* estimates welfare gains to urban households from reduced air pollution in the Indian cities of Delhi and Kolkata using the hedonic property price model. Primary data collected from the household surveys are used in the estimation of model. Alternative estimates of hedonic property price equation and the inverse demand function for atmospheric quality are obtained using the quadratic Box-Cox and trans log specifications. Usually in the empirical literature on hedonic property value models, quadratic Box-Cox specification of property price equation is found to be superior in terms of: (a) various hypotheses tested and (b) in displaying the required curvature property of both the hedonic price equation and inverse demand function for atmospheric quality. Estimates of welfare gains or consumer surplus benefits from reducing the air pollution from the current level to a safe level as defined by WHO or Indian MINAS standards for a representative household and all households in each city are obtained. The estimate of annual benefits from the reduced air pollution to all the households in Delhi and Kolkata are respectively, Rs.54833.1 millions and Rs.37026.2 millions.

JEL Classification: Q 25
Key words: Hedonic property prices, Urban air pollution, Welfare gains, Box-Cox

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I. Introduction

Commodities could be distinguished by the characteristics they possess and their prices are functions of these characteristics. From the point of view of the owner, land property could be distinguished in terms of its location, size, and local environmental quality, while from the worker's perspective, a job is a differentiated product in terms of the risk of an on job accident, working conditions, prestige, training and enhancement of skills, and the local environmental quality at the work place. Environmental characteristics like air or water quality affect the price of land either as a producer good or as a consumer good. Ridker (1967) and Ridker and Henning (1976) provided the first empirical evidence that air pollution affects the property values. Freeman (1974), and Rosen (1974) used the hedonic price theory to interpret the derivative of hedonic property price function with respect to air pollution as a marginal implicit price and therefore the marginal willingness-to-pay of individuals for air pollution reduction. Thaler and Rosen (1976) are the first to suggest that the labor market could be viewed as the hedonic market. The derivative of the hedonic wage function with respect to any job characteristic, say exposure to air pollution at work place, could be interpreted as the marginal implicit price or worker's marginal willingness to accept for increased exposure to pollution.

In a hedonic prices model therefore there are two equations to be estimated: The hedonic price function and the individual's marginal willingness-to-pay function for the improved environmental quality[1]. In the model of hedonic property prices estimated in this paper, the equations are given as:

$$P_{hi} = P_h (S_i, N_i, Q_i). \quad (1)$$

$$b_{ij} = b_{ij} (q_j, Q_i*, S_i, N_i, G_i). \quad (2)$$

Equation (1) is the hedonic price equation where P_{hi} is the property price[2] of the i^{th} house, S_i consists of the structural characteristics of the house, N_i contains the neighborhood characteristics of the house and Q_i stands for the Environmental characteristics of the house. Equation (2) is the individual's marginal willingness to `pay function where b_{ij} is the marginal willingness-to-pay for improved air quality for the j^{th} household, while Q_i^* is the vector of other environmental characteristics and G_i stands for socio-economic characteristics. q_j is the particular environmental characteristic for which we want to derive the marginal willingness-to-pay function.

[1] See Freeman (1974a) for the derivation of these equations using models explaining consumer choices of private goods, house property, jobs and environmental quality.

[2] Here the monthly rental value of the house is taken as a proxy for the property price.

There are a number of empirical studies[3], mainly in the developed country context, estimating the hedonic property value model for environmental values. The objective of these studies is to estimate the hedonic price and the individual's marginal willingness-to-pay functions with the required curvature properties. For example, one expects that property prices are an increasing function of the environmental quality given the characteristics of the house. Similarly, the individual's marginal willingness-to-pay is a decreasing function of environmental quality (inverse demand function for environmental quality)[4].

Obtaining estimates of these functions with the required properties depends upon: (a) Correctness of data used, and (b) Choice of appropriate functional forms. This paper, using the data collected through carefully designed household surveys in Delhi and Kolkata, the two important urban areas in India, explains the importance of choice of appropriate functional forms in the estimation of the hedonic property value model and provides estimates of consumer surplus benefits to households in both the cities from reducing air pollution to the safe level.

II. Choice of Functional Forms in Hedonic Price Models

The choice of functional form has usually been restricted both by theoretically unwarranted restrictions and by convenience in dealing with the problem at hand. As a result in most of the studies, a linear or a semi-log and at most a trans log model has been widely used. Griliches (1967) suggested the use of the Box Cox (1964) methodology for choosing among alternative functional forms under a relevant statistical framework. The early exception from the over restrictive theoretical framework was noted in Goodman (1978). The flexible functional form includes the quadratic, translog, square root quadratic, generalized square root and generalized Leontief. However, Halvorsen and Pollakowski (1981) provide a lucid discussion on the combination of the Box Cox and the flexible functional form approaches. They specify a generalized functional form, namely the quadratic Box Cox functional form, which yields all

[3] Ridker (1967) and Ridker and Henning (1976) provide the first empirical evidence that air pollution affects the property values. The early studies include Freeman (1974a; 1974b), Anderson and Crocker (1971; 1972), Lind (1973), Pines and Weiss (1976), Polinsky and Shavell (1976), Nelson (1978), Portney (1981), Horowitz (1986), Murdoch and Thayer (1988), and Kanemoto (1988). The most recent studies include the following: Michaels and Smith (1990), Parsons (1992), Lansford and Jones (1995), Kiel (1995), Kiel and McClain (1995), and Mahan, Polasky, and Adams (2000). Rrecent studies in India: are Parikh (1994), Sen (1994) and Murty, Gulati and Banerjee (2003).

[4] Some studies have failed to obtain inverse an demand function for environmental quality for example, Mahan, Polasky, and Adams (2000).

other functional forms as special cases. Blackley, James and Ondrich (1984) provide some evidence of the inappropriateness of using the iterative OLS technique and the Variance Bias, resulting there from, in the Box Cox estimates and advocate the use of a method of modified scoring.

The Quadratic Box-Cox Model

The general quadratic Box-Cox functional form for the hedonic property price equation (1) incorporating all other functional forms as special cases is given by:

$$P^{(q)} = a_0 + \sum_{i=1}^{m} a_i X_i^{(l)} + \frac{1}{2}\sum_{i=1}^{m}\sum_{j=1}^{m} g_{ij} X_{i=1}^{(l)} X_{j=1}^{(l)} \qquad (3)$$

where P is the price of property, X_i's are the characteristics of the house including structural, neighbourhood and environmental features, α_i and Υ_{ij}' s are the regression coefficients with coefficients Υ_{ij} = $\Upsilon_{ji,}$ for all i and j (i,j = 1,2,3,…m) and $P^{(q)}$ and $X^{(l)}$ are Box-Cox transformations as given below:

$$P^{(q)} = \left(P^{q} - 1\right)/q, \qquad \text{for all } \theta \neq 0$$

$$= \text{Ln P} \qquad \theta = 0$$

$$X_i^{(l)} = \left(X_i^{\,l} - 1\right)/\, l \qquad \text{For all } \lambda \neq 0$$

$$= \text{Ln } X_i \qquad \lambda = 0$$

The transformations are continuous around θ = 0 and λ = 0 since the limit for the θ ≠0 case as θ → 0 is Ln P and similarly the limit for λ≠0 case as λ→0 is Ln X_i. It can be easily found out that by imposing appropriate restrictions on θ and λ we can arrive at the more specific functional forms of interest. Imposing zero restrictions on θ and λ we can obtain the trans log form attributed to Christensen, Jorgenson and Lau (1971, 1973) given by:

$$LnP = a_0 + \sum_{i=1}^{m} a_i LnX_i + \frac{1}{2}\sum_{i=1}^{m}\sum_{j=1}^{m} g_{ij} LnX_i LnX. \qquad (4)$$

Similarly, imposing the restriction θ = λ =1 yields the quadratic form attributed to Lau (1974), imposing θ =2 and λ = 1 we obtain the square root form, (see Diewert, 1974) and with θ =1 and

λ = 1/2 we can attain the generalized nonhomogeneous version of the generalized Leontief form[5]. Adding a stochastic term to equation (3) we get: -

$$P^{(q)} = a_0 + \sum_{i=1}^{m} a_i X_i^{(l)} + \frac{1}{2}\sum_{i=1}^{m}\sum_{j=1}^{m} g_{ij} X_{i=1}^{(l)} X_{j=1}^{(l)} + e_t \qquad (5)$$

It is assumed that the true values of θ and λ are distributed normally and independently with zero mean and constant variance. The values of θ, λ, α_0, $\alpha_{i's}$, Υ_{ij} and σ^2 (where σ is the standard error of the regression) are estimated jointly by the maximum likelihood technique. The choice of θ and λ are such that they maximize the log likelihood function for the sample observations[6]. Most of the econometric packages[7] have routine programme to compute these estimates. The significance of the θ and λ in the respective regressions has been tested by the Chi-Squared test of the Wald-statistics. The same test of significance has been performed on the rest of the parameters of equation (3). The Likelihood ratio test is then employed to test the Null hypothesis of standard values of θ and λ (viz. $\theta = 0 = \lambda$, $\theta = 1 = \lambda$, and $\theta = -1 = \lambda$) separately against the alternative hypothesis of an unrestricted maximum likelihood estimate of θ and λ.

III. Data Sources and Design of Household Survey

Primary data on house characteristics and socio-economic conditions of 1250 respondents from the cities of Delhi and Kolkata were collected. The survey design was based on two stage stratified and circular systematic sampling procedures adopted in areas surrounding the functioning air pollution monitoring centres in the cities. The ambient air quality data of the study areas are collected from the publications of the Central Pollution Control Board (CPCB) and the West Bengal Pollution Control Board in India.

The information about socioeconomic characteristics of the household members inclusive of educational levels of adult members, occupational status, size, sex and age composition of the family members, and incomes are collected.

Information was elicited on type of house, structural characteristics, locational/ neighborhood characteristics comprising distances from highways, bus stops, schools/colleges, industrial

[5] For the derivation of these functional forms refer to Halvorsen and Pollakowski (1981)

[6] It may be noted that the Box-Cox transformation increases the chances for obtaining normally distributed residuals even though the maximum likelihood estimate does not try to choose θ and λ that make the residuals normally distributed, Box-Cox (1966).

[7] Stata 8 has been used for the current estimation and analysis.

complexes, public parks, etc. was also elicited. Further, information on community characteristics like majority religion, dominant professional group, and crime rate in the locality was collected. Information on the respondent's perception of the environmental conditions/characteristics such as the air quality, water quality, extent of green cover, etc. was also collected.

Detailed information on prices of properties was also elicited from the respondents. To cross check, the property prices obtained from the respondents in the survey, data on property prices were also collected from the property dealers in the surveyed areas. We surveyed 1250 households from each city expecting that information could be obtained completely for at least 1000 households per city. The sample size was divided equally around the functioning air pollution monitoring stations in the two cities. For illustration, the sample size of 1250 in Delhi was divided into a sub-sample size of around 180 around each of the 7 pollution-monitoring stations of the Central Pollution Control Board (CPCB). In Kolkata the sample size of around 65 was fixed around 19 air-pollution monitoring centres monitored by the West Bengal Pollution Control Boards (WBPCB). Ultimately, full information could be obtained only for 1187 households in Delhi and 1204 households in Kolkata. Thus, the first stage of stratification was geographic which was purposive in the sense that the localities around the monitoring stations were the selection criterion for the locality.

In the second stage, in each city the inhabited localities around the monitoring stations were stratified according to the type of locality adjudged by the standards of living of the inhabitants in terms of size of the houses, types of the houses such as bungalows/ independent houses or flats, type of conveyances used in general, etc. through physical verification by visiting the areas. At this stage, three localities one each from the high, medium and low income category were identified to draw a sample comprising a whole range of households in terms of socioeconomic status. The identification and mapping of localities selected for the survey has provided the necessary framework for selecting the households in the third stage. The selection of the targeted number of households was done by adopting a circular systematic sampling procedure in each selected locality nearer to the monitoring station.

IV. Model for Estimation and Measurement of Variables

The hedonic property value model consists of a set of two equations one representing the hedonic price function (1), and another representing the marginal willingness-to-pay function (2) for estimation. The two equations of the hedonic property value model estimated in this paper with Box Cox transformations of both dependent and independent variables are given below:

Hedonic Property Price Function:

$$(Y_1)^{(\theta)} = \alpha_1 + \beta_1(X_1)^{(\lambda)} + \beta_2(X_2)^{(\lambda)} + \beta_3(X_3)^{(\lambda)} + \beta_4(X_4)^{(\lambda)} + \beta_5(X_5)^{(\lambda)} + \beta_6(X_6)^{(\lambda)} + \beta_7(X_7)^{(\lambda)} + \beta_8(X_8) + \beta_9(X_9) + \beta_{10}(X_{10})^{(\lambda)} + \beta_{11}(X_{11}) + \beta_{12}(X_{12})^{(\lambda)} + \beta_{13}(X_{13})^{(\lambda)} + \beta_{14}(X_{14})^{(\lambda)} + \beta_{15}(X_{15})^{(\lambda)} + \beta_{16}(X_{16})^{(\lambda)} + \beta_{17}(X_{17})^{(\lambda)} + u_1 \quad \text{.......(6)}$$

Inverse Demand Function[8] or Individual Marginal Willingness-to-pay for Environmental Quality

$$(Y_2)^{(\theta')} = \alpha_2 + \gamma_{19}(X_{19})^{(\lambda')} + \gamma_{20}(X_{20})^{(\lambda')} + \gamma_{13}(X_{13})^{(\lambda')} + \gamma_{21}(X_{23})^{(\lambda')} + \gamma_{10}(X_{10})^{(\lambda')} + u_2 \quad \text{.......(7)}$$

where θ and λ are the transformations used in the hedonic price equation and θ` and λ` are the transformations used in the marginal implicit price function. Since these transformations apply only to positive values of Y and X, the constant and the dummy variables are not transformed. The model used in the empirical estimation contains only those variables that have provided significant Wald statistics and only one cross[9] product term (X_{20}) has turned out to be significant and has been used in the above model. The variables used in an estimation of the above two equations are described as follows:

Monthly rent (Y_1): Information on the monthly rents, for the house is collected from each household. Imputed monthly rental values were used for the owner-occupied houses in Delhi and

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[8] It might be noted that the literature on the hedonic property value model suggests the use of all the independent variables in the hedonic property price function also as independent variables in the willingness-to-pay function. We have two reasons for using the restricted functional form of the model reported in equation (7).
Firstly, it is the only one that satisfies the required curvature property of the inverse demand function for the entire relevant range of the atmospheric quality, given by the current average concentration of SPM to the safe level prescribed by WHO and the MINAS. The unrestricted willingness-to-pay estimate also satisfies the curvature properties of the inverse demand function but at a very stringent range of the atmospheric quality.
Secondly, the Box Cox transformation, as evident from the chi-square test, is relevant only for the restricted model and not for the unrestricted model and the transformed unrestricted model is even rejected in favour of the double log model. But the unrestricted double log model also fails to provide the required curvature properties of the inverse demand function. Thus the transformed Box Cox restricted model is the best fit in our search for an appropriate functional form for the willingness-to-pay function that renders all the properties of the inverse demand function and is also robust to all statistical tests of significance.
The estimates of the unrestricted model (only for the pooled model) and the inverse demand function are shown also in Table 6 and fig. 4, respectively.

[9] X_{20} is obtained as the square of X_{13}.

Kolkata. Data for monthly rents collected through the survey is compared with the information about the market rents and property prices collected from the interviews of property dealers from different localities in Delhi and Kolkata.

Structural Characteristics of the House

Covered area (X_1): Data for total covered area of the houses were collected directly from the households and the figures were reported in square yards. In the case of independent owner occupied or rented houses care was taken to exclude any uncovered area. For the flats, of course no such problems was encountered. In the case of multistoried buildings, the covered area was scaled for the number of floors.

Number of rooms including drawing rooms (X_2): The total number of rooms including drawing room were considered as a control variable for the monthly rental value of the house.

Indoor sanitation (X_3): The index for indoor sanitation was constructed out of the following information: separate kitchen, separate bathrooms and toilets, and condition of indoor ventilation. The index ranges from 0 to 6. Whenever a facility was found separately in a house it scored a value of 1 otherwise 0, in this way it can take up to a maximum value of 3 where separate kitchen, toilet and bathroom facilities are available. For ventilation, a scale of 1 to 3 was used with a higher number denoting better ventilation. These values were then added to arrive at the composite scale of 0 to 6.

Distance Characteristics:

Distance from business centre (X_4): The distance from any common business centre in the city was collected from each household.

Distance from national highways (X_5): The distance of the house from the national highways were collected and then an average distance was computed which proxies for the overall distance of the house from these national highways.

Distance from slum (X_6): Distance from the nearby slums was collected for area around each monitoring station in the cities separately.

Distance from industry (X_7): Distance from nearby industries for each monitoring station in each city was used to control for the extreme conditions of pollution in certain parts of the cities.

Distance from shopping centre (X_8): The distance from the nearest local shopping complex was collected for each monitoring station in the cities.

Environmental Variables:

Perception about air quality (X_{10}): This is an ordered variable in the range of 1 to 3, which is used to rank the locality in terms of the air quality as perceived by the households, the higher the rank, the higher the air quality available.

Perception about water quality (X_{12}): This is also an ordered variable in the range of 1 to 3, which is used to rank the locality in terms of the water quality as perceived by the residents of that area, the higher being the rank, the higher the water quality.

Dummy for Adequacy of Green Cover (X_{11}): This is a 1, 0 binary dummy variable, which is used to ascertain the perception of a household in any locality about the adequacy of the green cover (tree cover) in its location.

SPM (X_{13}): The average concentration of SPM in ì gms/m^3 in the last 6 months from the month of survey for a particular locality is used as the pollution variable.

SO_2 (X_{14}): The average concentration of SO_2 in ì gms/m^3 in the last 6 months for a particular locality is used as the pollution variable.

NO_x (X_{15}): The average concentration of NO_x in ì gms/m^3 in the last 6 months for a particular locality is used as the pollution variable.

Water supply (X_{16}): The hours of water supply in the particular locality.

Other variables:

Business or salaried class (X_9):A dummy variable assigning 1 to business communities and 0 to salaried class communities.

Variables for the Marginal Willingness-to-Pay Function:

Marginal willingness-to-pay (Y_2): The linear transformation of the marginal implicit prices for unit changes in the concentration of SPM or implicit marginal price for environmental quality is estimated using the following expression:

$$\frac{\partial Y_1}{\partial X_{13}} = \frac{X_{13}^{\,l-1}}{Y_1^{q-1}}\left(\boldsymbol{b}_{13}\right), \qquad (8)$$

where linear predicted household-specific values of Y_1 and the observed values of X_{13} have been used in the computation of the household-specific marginal implicit price. The modulus value of the above expression is used as the dependent variables in the marginal willingness-to-pay function.

Square of SPM (X_{20}): The square of SPM is used in the second equation keeping in mind the necessary curvature property of the willingness-to-pay function and its significance of Υ_{20} in the regression. It is expected that the pollution, SPM, positively related to the marginal willingness-to-pay for reduction in pollution. Alternatively the environmental quality is expected to be inversely related to the marginal willingness-to-pay. The descriptive statistics of all the selected variables are presented in the Appendix (Tables A1, A2 and A3).

City Dummy (X_{23}): All the observations belonging to Delhi are marked as 1 and all observations belonging to Kolkata are marked as 0 in the pooled model.

Socio-economic Variables

Education in years (X_{18}): The education variable is constructed by adding the years of education undertaken by the first five adult members of the family and dividing by 5.

Annual gross family income (X_{19}): This is based on the gross annual family income of the household. In the absence of any concrete figures for actual incomes for certain households it was necessary to offer certain income brackets to the respondents to choose from.

V. Estimates of Hedonic Property Value Model Under Alternative Functional Forms

Estimates of the hedonic property price function for Delhi under the general quadratic Box Cox estimation and the trans log functional forms are provided in Table 1. In both the estimates the structural variables like Covered Area (X_1), Number of rooms (X_2), Indoor sanitation (X_3) show the correct sign and is significant at the 1% level. Among the distance characteristics variables Distance form Business centre (X_4), Distance from industries (X_7) and Distance from national highway (X_5) are also significant at 1% and bear the correct sign. Distance from slums (X_6) and the dummy for availability of slum (X_8) have proper signs and are significant at the 1% level. The variables measuring the distance from shopping centre (X_{17}) has a positive coefficient and it is also significant in the unrestricted model.

It is also noted that the presence of business class (X_9) affects house rents significantly in both the model estimates. The Environmental variables like Perception about air quality (X_{10}), Adequacy of green cover (X_{11}) and Perception about water quality (X_{12}) have expected signs in both the models but they are not significant. Even hours of water supply (X_{16}) do not seem to

Table: 1 Estimates of Hedonic Price Equation for Delhi.

Dependent variable Monthly House Rent		
Variables (Expected Signs)	Trans log Model $\theta = 0$ $\lambda = 0$	Box Cox Transformation $\theta = 0.0765446$*** $\lambda = -0.1064827$*
	Coefficients (t-statistics)	Coefficients (Chi^2 statistics)
Constant	10.23759*** (11.37)	19.53819
Covered Area: X_1 (+)	0.183950*** (3.95)	0.5438875*** (19.883)
No. of Rooms: X_2 (+)	0.646681*** (9.30)	1.466924*** (167.047)
Indoor Sanitation: X_3 (+)	0.464654*** (4.39)	1.023839*** (25.667)
Distance from Business Centre: X_4 (+)	0.143340*** (4.59)	0.2859844*** (16.481)
Distance from National highways: X_5 (+)	0.051224*** (3.36)	0.0948012*** (16.481)
Distance from Slums: X_6 (+)	0.202827*** (3.22)	0.4425801*** (13.032)
Distance from Industries: X_7 (+)	0.144710*** (3.03)	0.3456081*** (12.303)
Dummy for Slums: $^{\$}X_8$ (-)	-0.257561*** (-4.17)	-0.5026985*** (16.009)
Dummy for Business or salaried class: $^{\$}X_9$ (+)	0.173580*** (3.43)	0.3713925*** (15.379)
Perception about Air Qlty: X_{10} (+)	0.089259 (1.22)	0.1493541 (1.040)
Adequacy of Green Cover: $^{\$}X_{11}$ (+)	0.044258 (0.89)	0.0933311 (1.213)
Perception about water Qlty: X_{12} (+)	0.060599 (0.86)	0.1530054 (1.364)
SPM: X_{13} (-)	-0.658795*** (-5.59)	-2.644776*** (38.595)
SO_2: X_{14} (-)	0.142859* (1.62)	-0.922619*** (9.604)
NO_x: X_{15} (-)	-0.268090*** (-2.63)	0.446201** (4.034)
Water Supply in Hrs: X_{16} (+)	-0.033733 (-1.23)	-0.091236 (2.264)
Distance from Shopping Centre: X_{17} (-)	0.019048 (1.30)	0.0406528* (3.303)
Uncentred R^2	0.4504	Sigma = 1.421134
Adjusted R^2	0.4424	LR chi^2 (18) = 733.67 Probability > Chi^2 = 0.000 Uncentred R^2 = 0.618
		Log Likelihood = -11585.625
Likelihood ratio test		
Test H_0	Restricted Log likelihood	Chi^2 Statistics
$\theta = -1 = \lambda$	-14875.305	6579.36***
$\theta = 0 = \lambda$	-11599.854	28.46***
$\theta = 1 = \lambda$	-12809.207	2447.16***

Note: *(**) & (***) denotes significance at 10 (5) & (1) % levels. $ denotes variable without transformation.

affect house rents significantly. The coefficient of the pollution variable, SPM concentration (X_{13}) is highly significant and has the expected sign in both the models. Given that pollution concentrations of SO_2 and NOx are quite within the safe limits we believe a further reduction or a slight increase in their concentration would not affect house rents significantly. The uncentred R^2 is computed for both the models and it is much higher in the unrestricted model. Other standard diagnostic tests were performed on these models and both the models are free from any serious problem[10]. The likelihood ratio test is also performed on each of the independent variables and there was no problem of convergence encountered in the process[11].

The Likelihood ratio test is employed to test the Null hypothesis of standard values of θ and λ (viz. $\theta = 0 = \lambda$, $\theta = 1 = \lambda$ and $\theta = -1 = \lambda$) separately against the alternative hypothesis of unrestricted maximum likelihood estimates of θ and λ. The tests reject the null hypothesis of θ and λ to be of any of the above standard form against the alternative of unrestricted θ and λ in all the models estimated in the paper. Thus the quadratic Box Cox estimation is superior when compared to the parametric estimates of the trans log model (or any other restricted model) thereby highlighting the importance of the appropriate choice of the functional form for the hedonic price equation.

The linear predictions of the house rents Y_1, were computed from the model estimates of the hedonic price equation using the appropriate reverse transformation and these were used to compute the house specific estimates of the marginal implicit prices as shown by equation (8) above. The expression for Delhi is given by[12]:

$$\left| \frac{\partial Y_1}{\partial X_{13}} \right| = \left| \frac{X_{13}^{l-1}}{Y_1^{q-1}} (-2.644776) \right| . \tag{9}$$

The household marginal willingness-to-pay function for the reduction in SPM is estimated by regressing the implicit marginal prices on income, education and other socioeconomic variables and the SPM concentration and its square. Table 2 provides the parametric estimates of the marginal willingness-to-pay function under the two models. For this function the standard Z test does not reject the null hypothesis that lambda is equal to zero even at the10% level of significance

[10] The White's heteroscedasticity corrected standard errors are reported.

[11] For a detailed discussion in the estimation method consult Stata 8 Reference Manual (Vol. 1, A to F).

[12] For the trans log model theta and lambda are zero and hence equation (13) reduces to the ratio of X_{13} to Y_1 times the coefficient (-0.658).

Table 2: Estimates of Marginal Willingness-to-pay Equation for Delhi.

Dependent Variable Marginal Rent		
Log Values of Variables (Expected Sign)	Trans log Model $\theta = 0$	Box Cox Transformation $\theta = 0.0736085$**
	Coefficients (t-statistics)	Coefficients (Chi^2 statistics)
Constant	-43.17935*** (-3.61)	-0.5406424
Education X_{18} (+)	0.430238*** (5.87)	0.0316471*** (53.814)
Income X_{19} (+)	0.538860*** (13.76)	2.6e-06*** (294.164)
SPM X_{13} (+)	14.32783*** (3.51)	0.0117879*** (71.954)
Sq SPM X_{20} (-)	-1.336191*** (-3.89)	-0.0000166*** (90.493)
Perception about Air Quality X_{10} (+)	0.270875*** (3.46)	0.1780826*** (43.498)
		Sigma = 0.5686012
Uncentred R^2 Adjusted R^2	0.357199 0.354477	LR chi ^{2} (5) = 658.27 Probability > Chi^2 = 0.000 Uncentred R^2 = 0.555
		Log Likelihood = -3707.6189
Likelihood ratio test		
Test H_0	Restricted Log likelihood	Chi ^{2} Statistics
$\theta = -1$	-4350.042	1284.85***
$\theta = 0$	-3710.2565	5.28**
$\theta = 1$	-4070.3201	725.40***

Note: *(**) & (***) denotes significance at 10 (5) & (1) % levels.

so the Box Cox transformation has been employed only to the dependent variables for which the standard Z statistic is significant at the 5% level.

For the marginal implicit price function[13] the socio-economic variables like Education (X_{18}), Gross annual household income (X_{19}) and the Perception for air quality variable (X_{10}) bear an expected positive sign and are significant at the1% level for both the model estimates. There is a

[13] The marginal implicit price for each household derived from the hedonic property price function using equation 9, is not an observed variable. In the context of regression on derived variables Feenstra and Hanson (1997, 1999), Haskel and Slaughter (2001, 2002) and Dumont et. al. (2003) suggest different methods of correcting the standard errors of the parametric estimates. All the methods suggest a reduction of the standard error of the parametric estimate for gaining efficiency. Since our parametric estimates are highly significant with this enlarged standard error (uncorrected) bands, we can safely expect them to be significant with further reduction in the standard error. Thus this correction seems redundant in our case. On the other hand, Noboru Hidano (2002) suggests that the problem of identification in case of the marginal implicit price function can be avoided by using higher order functional forms for the hedonic price function than the marginal implicit price function. In this context it may be noted that since the Box Cox transformation uses different functional forms for the two sets of equations this problem of identification is also overcome. Further, in the case of the hedonic price function, in all the cities and in the pooled model as well, a both side transformation with separate parametric values of theta and lambda has been found statistically suitable whereas in the marginal implicit price function only the right hand side transformation is statistically significant. So it is evident that a different functional form has been assumed for estimating the two equations and the problem of identification does not arise.

notable distinction in the signs of X_{13} and X_{20} (pollution variables) in the two models. Only parametric estimates of the unrestricted Box Cox estimation satisfy the required curvature property of the marginal willingness-to-pay function.

Table 3 provides the parametric estimates of hedonic property price function for Kolkata. In the case of Kolkata, the Box-Cox transformation is given only to the dependent variable, as the transformation of the independent variables does not produce any significant change in the regression as is evident by the Chi^2 test. The likelihood ratio test rejects the H_0 for all the standard values of θ tested against the unrestricted value of θ.

In the unrestricted model the regression coefficient for (X_{13}) is quite small when compared to the same for the Delhi model. However it is highly significant and bears the correct negative sign. We are again indifferent to the signs picked up by the coefficients of (X_{14}) and (X_{15}) for the reasons stated above. Among the structural characteristics, the coefficients of (X_3) and (X_2) have required positive signs and are highly significant while the coefficient of (X_1) bears the opposite sign and is insignificant in the trans log model while in the unrestricted model it is significant. The dummy for Slums X_8 is significant and negative in both the models while the distance characteristics produce mixed results for Kolkata as a whole[14]. Similar to the model for Delhi, the linear predictions for (Y_1) are computed using expression (8) to get the household specific marginal implicit prices. In this case however exogenous variables are not transformed and so the expression for the marginal implicit price is:

$$\left| \frac{\partial Y_1}{\partial X_{13}} \right| = \left| \frac{1}{Y_1^{q-1}} (-0.0587933) \right| \qquad (10)$$

The estimates of marginal willingness-to-pay function for Kolkata are given in Table 4 below. The coefficients of all the explanatory variables except Income (X_{19}) bear the correct sign and are highly significant. Even in case of Kolkata the unrestricted model shows the household diminishing marginal willingness-to-pay for the atmospheric quality.

Two separate estimates of the marginal willingness-to-pay function are made using the pooled data for Delhi and Kolkata. One estimate is based on the hedonic property price functions estimated for the segmented house markets Delhi and Kolkata. The implicit marginal prices for SPM reductions are computed for each market and then pooled. The pooled implicit marginal

[14] They are still more effective in case of the unrestricted model (e.g. X_5 and X_{17}).

Table3: Estimates of Hedonic Price Equation for Kolkata.

Dependent variable Monthly House Rent		
Variables (Expected Signs)	Trans log Model $\theta = 0$ $\lambda = 0$	Box Cox Transformation $\theta = 0.3681178$***
	Coefficients (t-statistics)	Coefficients (Chi^2 statistics)
Constant	10.58682*** (14.39)	35.29286
Covered Area: X_1 (+)	-0.026117 (-1.06)	-0.000507* (2.716)
No. of Rooms: X_2 (+)	0.955376*** (14.82)	2.488142*** (294.673)
Indoor Sanitation: X_3 (+)	0.291560*** (3.12)	1.817918*** (29.506)
Distance from Business Centre: X_4 (+)	0.137361*** (5.57)	0.2563974*** (12.624)
Distance from National highways: X_5 (+)	0.061320 (0.94)	0.974085** (6.240)
Distance from Slums: X_6 (+)	0.150310 (1.34)	-0.0110185 (0.001)
Distance from Industries: X_7 (+)	0.051119 (0.70)	-0.1726866 (0.096)
Dummy for Slums: $^{\$}X_8$ (-)	-0.379371*** (-5.59)	-4.930523*** (31.733)
Dummy for Business or salaried class: $^{\$}X_9$ (+)	0.056327* (1.62)	1.455582*** (7.164)
Perception about Air Qlty: X_{10} (+)	0.050404 (0.78)	0.5017189 (0.709)
Adequacy of Green Cover: $^{\$}X_{11}$ (+)	0.087828* (1.74)	2.303671** (5.546)
Perception about water Qlty: X_{12} (+)	0.173977** (2.33)	-0.5017189 (0.823)
SPM: X_{13} (-)	-0.719903*** (-7.13)	-0.0587933*** (71.564)
SO_2: X_{14} (-)	0.174656 (1.13)	0.4905682** (5.461)
NO_x: X_{15} (-)	-0.177321* (-1.88)	0.014077 (0.738)
Water Supply in Hrs: X_{16} (+)	0.034463 (0.95)	0.1109009* (2.888)
Distance from Shopping Centre: X_{17} (-)	-0.044881 (-0.71)	0.9406537*** (7.249)
Uncentred R^2	0.3873	Sigma = 13.44937
Adjusted R^2	0.3786	LR chi^2 (17) = 526.88 Probability > Chi^2 = 0.000 Uncentred R^2 = 0.4376
		Log Likelihood = -10836.371
Likelihood ratio test		
Test H_0	Restricted Log likelihood	Chi^2 Statistics
$\theta = -1$	-13365.004	5057.26***
$\theta = 0$	-11022.034	371.33***
$\theta = 1$	-11462.206	1251.67***

Note: *(**) & (***) denotes significance at 10 (5) & (1) % levels. $ denotes variables without transformation.

Table 4: Estimates of Marginal Willingness-to-pay Equation for Kolkata

Dependent Variable Marginal Rent		
Log Values of Variables (Expected Sign)	Trans log Model $\theta = 0$	Box Cox Transformation $\theta = 0.4792194$**
	Coefficients (t-statistics)	Coefficients (Chi^2 statistics)
Constant	-22.96979** (-2.48)	3.069313
Education X_{18} (+)	0.796318*** (6.94)	0.0119188*** (22.779)
Income X_{19} (+)	0.571237*** (11.52)	-2.42e-07*** (9.191)
SPM X_{13} (+)	6.737927** (2.07)	0.0021936*** (10.354)
Sq SPM X_{20} (-)	-0.693091** (-2.42)	-3.63e-06*** (11.905)
Perception about Air Quality X_{10} (+)	0.173072*** (3.30)	0.0336502*** (10.415)
		Sigma = 0.5686012
Uncentred R^2 Adjusted R^2	0.333585 0.330727	LR chi ^{2} (5) = 61.23 Probability > Chi^2 = 0.000 Uncentred R^2 = 0.50
		Log Likelihood = -3707.6189
Likelihood ratio test		
Test H_0	Restricted Log likelihood	Chi ^{2} Statistics
$\theta = -1$	-1421.3999	49.53***
$\theta = 0$	-1399.136	5.01**
$\theta = 1$	-1399.4891	5.71**

Note: *(**) & (***) denotes significance at 10 (5) & (1) % levels.

prices are regressed on the SPM levels and the socioeconomic characteristics of households along with a city specific dummy variable (X_{23}). This is one approach to deal with the econometric problem of identification in the estimation of the household marginal willingness-to-pay function in the hedonic property value model as discussed in Freeman (1993). Another estimate is based on the hedonic property price function estimated using the pooled data for Delhi and Kolkata. However, we are reporting the results of only the marginal willingness-to-pay function for the pooled model estimated by using the market segmentation approach[15].

The parametric estimates of the two models have the proper sign and are highly significant. In this case also, the curvature property is satisfied by the unrestricted model only. The likelihood ratio test rejects H_0 for all standard forms of θ and thus the unrestricted model is unambiguously superior to the trans log counterparts[16] in the estimates for both the cities as well as the pooled

[15] The complete set of results of the pooled model is available on request from the authors.
[16] All standard transformations are rejected in favour of the unrestricted quadratic Box Cox transformation.

model. Further, only by following the segmented market approach in the case of pooled model estimates, the required curvature property was satisfied.

Table 5: Estimates of Marginal Willingness-to-pay Equation for the pooled model

Dependent Variable Marginal Rent		
Log Values of Variables (Expected Sign)	Trans log Model $\theta = 0$	Box Cox Transformation $\theta = 0.4792194$**
	Coefficients (t-statistics)	Coefficients (Chi^2 statistics)
Constant	-30.62877*** (-5.25)	0.4782014
Education X_{18} (+)	0.558753*** (9.23)	0.013794*** (88.590)
Income X_{19} (+)	0.554709*** (18.01)	8.87e-07*** (325.828)
SPM X_{13} (+)	9.689258*** (4.77)	0.0052934*** (228.374)
Sq SPM X_{20} (-)	-0.950415*** (-5.42)	-7.7e-06*** (258.450)
Perception about Air Quality X_{10} (+)	0.221595*** (5.05)	0.0477618*** (40.216)
City Dummy X_{23} (+)	0.790453*** (21.48)	0.214818*** (327.223)
		Sigma = 0.2530792
Uncentred R^2 Adjusted R^2	0.42295 0.42148	LR chi ^{2} (6) = 1096.25 Probability > Chi^2 = 0.000 Uncentred R^2 = 0.46372
		Log Likelihood = -6373.6493

Likelihood ratio test		
Test H_0	Restricted Log likelihood	Chi ^{2} Statistics
$\theta = -1$	-7116.5125	1485.73***
$\theta = 0$	-6400.8154	54.33**
$\theta = 1$	-7502.4537	2257.61**

Note: *(**) & (***) denotes significance at 10 (5) & (1) % levels.

Ideally, one could expect that the similar sets of structural and neighbourhood variables (as used in the estimation of the Hedonic price function) along with the environmental and socioeconomic characteristics determine the marginal willingness-to-pay for environmental quality. However in the current study, it has been observed that the parametric estimates of the pollution variables remain unaffected with the inclusion of the structural and environmental characteristics in the marginal willingness-to-pay function. The robustness of the parametric estimates can be attributed to the weak separability between the Environmental variables with the Structural and Neighbourhood characteristics while determining the marginal willingness-to-pay for clean air. The parametric estimate of the unrestricted[17] marginal willingness-to-pay is provided in Table 6 below. The Likelihood ratio test rejects the double log model as well as all other standard

[17] Using all the independent variables that were used in the hedonic price function.

functional forms of the marginal willingness-to-pay function in favour of the both sides transformed unrestricted model. Also in the both sides transformation model the individual z-test rejects the null hypothesis that the true value of λ and θ are zero. However all single-sided transformations or double-sided transformation with the same parameter of the unrestricted model are rejected in favour of the double log model and render insignificant parametric estimates of λ and θ as well. Thus it is easy to conclude that the both side transformation model is more appropriate than any other model in terms of statistical analysis. But unfortunately, even the both side transformation model fails to offer the required curvature property of the inverse demand function in the relevant range[18], just as any other functional form of the unrestricted model. Figure 4 represents the inverse demand function estimated form the unrestricted model. The market segmentation approach has been followed for all the pooled data estimates.

The unrestricted willingness-to-pay function fails to provide the required curvature properties in the individual city-specific[19] models as well. Thus the welfare gains obtained from a reduction of air pollution have been computed only from the restricted model of the marginal willingness-to-pay function.

[18] The relevant range is defined as the current average concentration of SPM to the WHO, MINAS prescribed safe level of 200 μ gm/m^3.

[19] These estimates are not reported here.

Table 6: Estimates of Marginal Willingness-to-pay Equation for the pooled model (Unrestricted)

Dependent Variable Marginal Rent			
Box Cox Transformation parameters			
Theta = -0.0526165 ***			
Lambda = -0.3364357***			
Variables	Coefficients (Chi^2 statistics)	Variables	Coefficients (Chi^2 statistics)
Constant	-316.5959	Dummy for Business or salaried class: $^{\$}X_9$	0.3092857*** (26.029)
Covered Area: X_1	0.826*** (431.178)	Perception about Air Qlty: X_{10}	0.0274651*** (13.754)
No. of Rooms: X_2	0.0340558*** (332.138)	Adequacy of Green Cover: $^{\$}X_{11}$	0.0043971*** (0.187)
Indoor Sanitation: X_3	0.0495319*** (140.092)	Perception about water Qlty: X_{12}	0.0107325** (4.572)
Distance from Business Centre: X_4	0.0631395*** (129.693)	SPM: X_{13}	-42.17456*** (408.905)
Distance from National highways: X_5	0.0312554*** (331.616)	Sq SPM X_{20}	141.5829*** (404.324)
Distance from Slums: X_6	0.2264228*** (198.459)	Water Supply in Hrs: X_{16}	-0.0302438*** (8.623)
Distance from Industries: X_7	0.1892529*** (728.652)	Distance from Shopping Centre: X_{17}	0.0093668*** (35.112)
Dummy for Slums: $^{\$}X_8$	-0.2085701*** (858.672)	LR chi ^{2} (20) = 2929.85 Probability > Chi^2 = 0.000 Uncentred R^2 = 0.78 Log Likelihood = -5268.4761	
Likelihood ratio test			
Test H_0	Restricted Log likelihood	Chi ^{2} Statistics	Test H_0
$\theta = -1$	-6449.8946	2362.84***	$\theta = -1$
$\theta = 0$	-5541.989	547.03***	$\theta = 0$
$\theta = 1$	-6674.0822	2811.21***	$\theta = 1$

Note: *(**) & (***) denotes significance at 10 (5) & (1) % levels.

V. Inverse Demand Functions for Environmental Quality and Welfare Gains from Reduced Air Pollution

By fixing variables X_{18}, X_{19} and X_{10} in the estimated[20] equations of marginal willingness-to-pay at their sample mean values, and treating pollution variables (X_{13}) and (X_{20}) as the only variable, the inverse demand function[21] for clean air was derived. After applying the appropriate reverse transformation, the linearized[22] predicted values of marginal willingness-to-pay (MWP) in the

[20] Given in Tables 2, 4 and 6 for Delhi, Kolkata and the Pooled model, respectively.
[21] This is also the marginal willingness-to-pay function for clean air.
[22] The reverse linear transformation refers to the $Y = (1 + \theta\alpha_0 + \theta\Sigma\alpha_i X_i)^{1/\theta}$ in which anything other than X_{13} and X_{20} are set at their mean values.

inverse demand functions for Delhi, Kolkata and the Pooled model are given by equations (11), (12) and (13). The reverse transformation is necessary in order to express the predicted values of marginal willingness-to-pay, out of the Box Cox transformed variables, in the actual rupee values, given that Monthly rent (Y_1) is expressed in rupees.

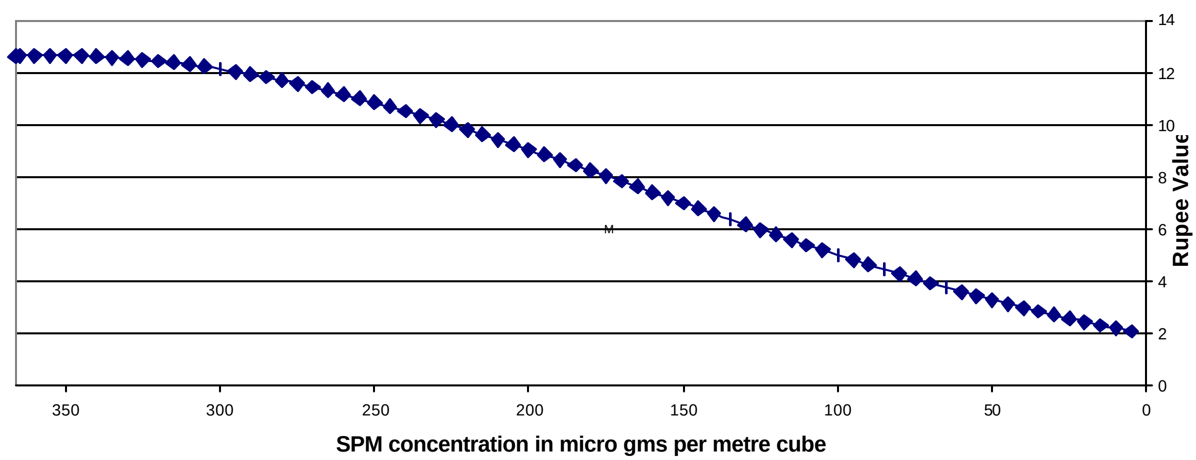
$$MWP = [1.051322 + 0.0008677\, X_{13} - 0.0000012\, X_{20}]^{13.585} \quad \text{[Delhi]} \quad (11)$$

$$MWP = [2.560514 + 0.0010512\, X_{13} - 0.0000017\, X_{20}]^{2.0867} \quad \text{[Kolkata]} \quad (12)$$

$$MWP = [0.826114 + 0.0009079\, X_{13} - 0.0000013\, X_{20}]^{13.585} \quad \text{[Pooled]} \quad (13)$$

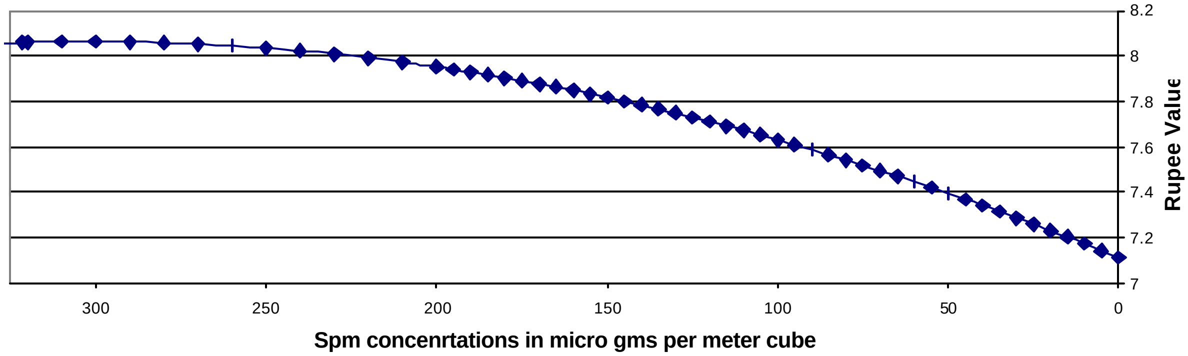
From the above estimates of the inverse demand function the marginal willingness-to-pay, for a typical household, for a reduction in SPM concentration by one micro gram per metre cube from the current average level of pollution, is computed as Rs.12.63 for Delhi, Rs.8.06 for Kolkata and Rs.10.21 for a representative household in the pooled model. By using suitable dummies for the cities and the city-specific SPM concentrations the willingness-to-pay for reduction in SPM concentration by one micro gram per meter cube from the current average level of pollution, is computed as Rs.12.01 in Delhi and Rs.8.74 in Kolkata from the pooled model. The marginal willingness-to-pay estimated from the individual estimates are thus very close to the estimates obtained from the pooled model. This shows that the pooled model may be used for extrapolation of consumer surpluses for any representative city in India using the benefit transfer method. The graphs of inverse demand functions are shown in figs. 1, 2 and 3, respectively for Delhi, Kolkata and the pooled model. The SPM concentration is shown in reversed scale on the X-axis to represent ambient air quality and MWP is shown on the Y-axis

Figure 1: Inverse demand function for clean air in Delhi



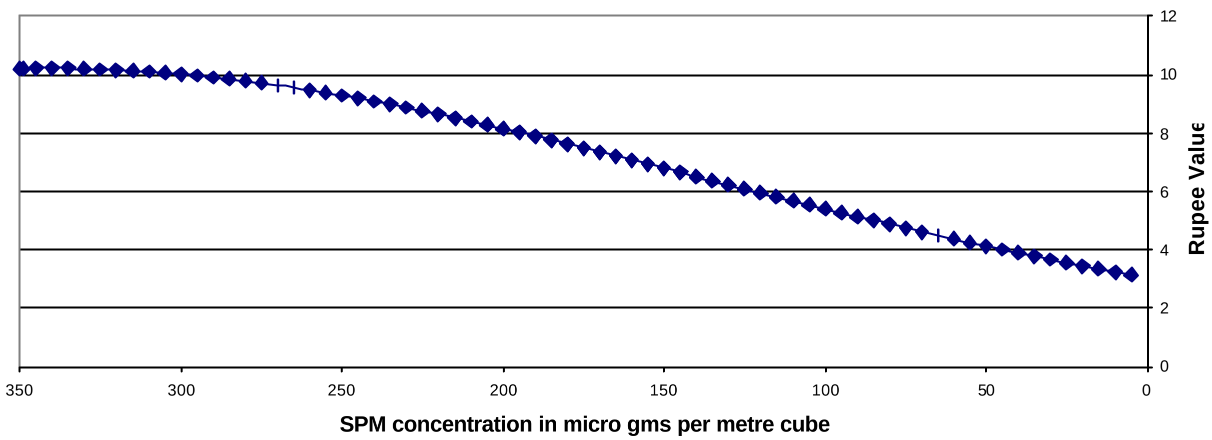
Note: The graph is generated from the Current average level of SPM of 366.31 μ gm/m³ to zero SPM, while the safe limit for SPM concentration is 200 μ gm/m³.

Figure 2: Inverse Demand function for clean air in Kolkata



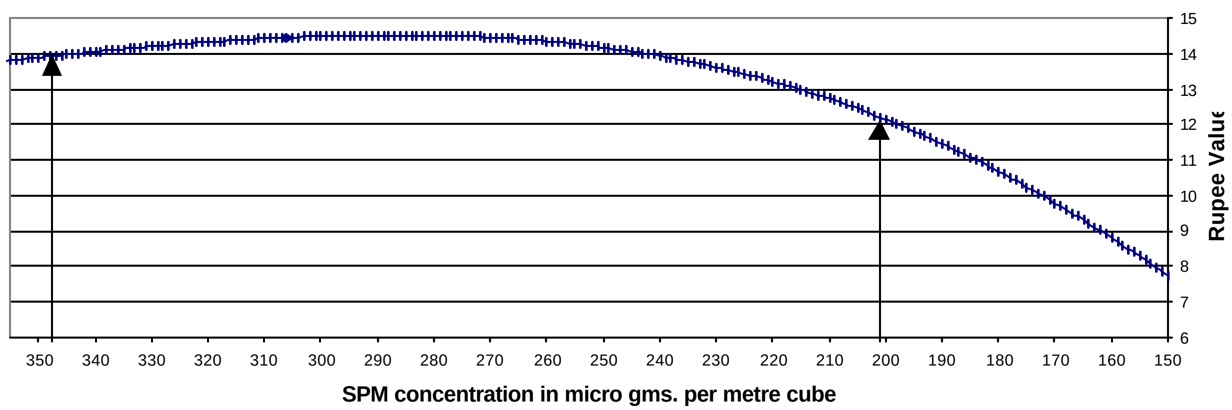
Note: The graph is generated from the Current average level of SPM of 321.39 µ gm/m³ to zero SPM, while the safe limit for SPM concentration is 200 µ gm/m³.

Figure 3: Inverse Demand Function for the Pooled model of Delhi and Kolkata



Note: The graph is generated from the Current average level of SPM of 349.09 µ gm/m³ to zero SPM, while the safe limit for SPM concentration is 200 µ gm/m³.

Figure 4: Inverse Demand Function for the Pooled model (Unrestricted model)



Note: The graph is generated from the Current average level of SPM of 349.09 µ gm/m³ to zero SPM, while the safe limit for SPM concentration is 200 µ gm/m³.

Table 7: Estimates of Welfare Gains to Urban Households in Delhi, Kolkata and for the Pooled Model

Nature of Gains to Households	Gains to Household Based on Individual Estimates from Cities		Gains to Household Using Market Segmentation Approach[23]		
	Delhi	**Kolkata**	**Delhi**	**Kolkata**	**Pooled**
Monthly gains in Rental value due to reduction of SPM concentration by 1 ì gms/m^3	Rs.12.63	Rs.8.06	Rs.12.01	Rs.8.74	Rs.10.21
Monthly gains in Rental value due to reduction of SPM concentration from the current average to the safe level corresponding to 200 ì gms/m^3	Rs.1946.14	Rs.977.22	Rs.1887.65	Rs.980.69	Rs.1420.61
Annual gains in Rental value due to reduction of SPM concentration by 1 ì gms/m^3	Rs.151.56	Rs.96.72	Rs.144.12	Rs.104.88	Rs.122.52
Annual gains in Rental value due to reduction of SPM concentration from the current average to the safe level corresponding to 200 ì gms/m^3	Rs.23353.68	Rs.11726.59	Rs.22651.80	Rs.11768.28	Rs.17047.32
Annual gains in Rental value due to reduction of SPM concentration from the current average to the safe level corresponding to 200 ì gms/m^3 to the total Urban Households[24].	Rs.54833.08 Million	Rs.37026.16 Million	Rs.53185.10 Million	Rs.37157.78 Million	Rs.92612.69 Million[25]

[23] The estimates of individual cities are calculated by using the city-specific dummy and the city's average level of pollution.
[24] The total urban population is obtained from Census 2001 data and deflated by the average size of household in the respective cities which is 5.46 for Delhi and 4.56.for Kolkata.
[25] The total urban population of Delhi and Kolkata is used to evaluate the total gains

The consumer surplus generated by a reduction of SPM concentration from the current average to the safe level of 200 μ gm/m^3 is computed by integrating the inverse demand function given by equations (11) to (13) within 200 μ gm/m^3 as the lower limit[26] and the current average level of pollution in the respective cities as the upper limit. Integration of the inverse demand functions were carried out in Mathematica[27] 4.1 and the results of the consumer surpluses are provided in Table 7 above. The estimated consumer surplus also measures the average willingness-to-pay by a representative household for reduction in the ambient air pollution from the current average to the safe WHO or MINAS[28] standards. The annual welfare gains to a typical household from reducing SPM concentration from the current level to the MINAS standard of 200 ì gms/m^3 in Delhi, and Kolkata are respectively, Rs.23353.68 and Rs.11726.59. According to 2000 census, Delhi and Kolkata have urban populations of 12.8 millions, and 14.4 millions with sample average household sizes of 5.46 and 4.56, respectively. Thus there are 23,47,942, and 31,57,452 estimated urban households in Delhi and Kolkata. The annual benefits from reducing the SPM concentration to safe level in Delhi and Kolkata are respectively estimated as Rs.54,833.08 million and Rs.37,026.16 million. The estimates of welfare gains to the two cities as computed form the Pooled model are also given in Table 7. These estimates are very close to the individual estimates of gains in these cities. This shows the robustness of the pooled model that may be used in extrapolating welfare gains from a reduction in air pollution in some other metropolitan centres in India. The welfare gains are not computed from the trans log model, as the required curvature properties are not satisfied by the inverse demand function.

VI. Conclusion

Empirical studies using the observed behavioral methods (household production function and hedonic prices models) look for the derivation of an inverse demand function or marginal willingness-to-pay function for the environmental quality with appropriate curvature properties for an estimation of the consumer surplus benefits from the improved environmental quality. The failure to obtain an inverse demand function in some empirical studies might arise either due to: (a) the poor quality of data used and (b) inappropriate functional form used for the estimation of hedonic price and willingness-to-pay functions. We have shown that given the reliable data, the

[26] 200 μ gm/m^3 is the safe WHO and MINAS standard for residential area in India.
[27] Software for Mathematical Solutions.
[28] MINAS: Minimum National Standards for Environmental Pollution in India.

inverse demand function with the required properties could be derived with the choice of appropriate functional form for the hedonic property price and the marginal willingness-to-pay equations. Starting from a more general quadratic Box Cox functional form for the hedonic price function a number of functional forms could be considered and tested for their appropriateness.

The hedonic property price function is estimated using the primary data collected for house characteristics through carefully designed household surveys in Delhi and Kolkata. Estimates of consumer surplus benefits to a representative household from each city are obtained by integrating the inverse demand function for air quality in the range of current average quality and the quality corresponding to safe level.

A representative household gets an annual benefit of Rs.23,353.68 in Delhi and Rs.11,726.59 in Kolkata. When the benefits are extrapolated to all the urban households in each city, the households in Delhi get benefits worth Rs.54,833.08 million while those in Kolkata get benefits worth Rs.37,026.16 million. Though these benefits appear to be high, they are not so in comparison to the cost to various economic agents like the Government and polluters to reduce the air pollution levels from the current level to the safe level. In fact these benefit estimates justify the cost of environmental policy changes like introducing CNG operated vehicles, and substituting the metro rail in place of road transport and the relocation of polluting industries in the cities.

Appendices

Table A1: Descriptive Statistics of the Variables Used for Estimation of the Hedonic Property Value Model: Location Delhi

	Rent (Rs/month) (Y_1)	Covered area (Sq yards) (X_1)	Number of rooms (X_2)	Indoor sanitation Index (X_3)	Distance from Business Centre (Km) (X_4)	Distance from National Highway (Km) (X_5)
Mean	9536.612	136.9534	4.096040	4.462511	4.992334	1.279174
Std. Dev.	13725.58	342.6036	2.527597	1.148752	4.975135	1.397169
Observations	1187	1187	1187	1187	1187	1187

	Distance from Slum (Km) (X_6)	Distance from Industry (Km) (X_7)	Dummy for Nearby Slums (X_8)	Dummy for Business Community (X_9)	Perception of Air Quality Index (X_{10})	Index for Adequacy of Green Cover (X_{11})
Mean	1.594302	1.330526	0.571188	0.541702	2.144903	0.622578
Std. Dev.	1.217707	1.317624	0.495115	0.498468	0.623511	0.547041
Observations	1187	1187	1187	1187	1187	1187

	Perception about drinking water (X_{11})	SPM (X_{13})	SO_2 (X_{14})	NO_2 (X_{15})	Water Supply (Hours / day) (X_{16})	Distance from Nearest Shopping Centre (Km) (X_{17})
Mean	2.127211	366.3136	12.96807	36.45013	5.998678	2.788031
Std. Dev.	1.113989	86.42897	4.088191	13.13383	5.958350	3.247169
Observations	1187	1187	1187	1187	1187	1187

	Education Index (Years) (X_{18})	Gross annual Family Income (Rs) (X_{19})	SPM*SPM (X_{20})	
Mean	12.29264	179565.3	141649.4	
Std. Dev.	4.238082	127156.2	69776.29	
Observations	1187	1187	1187	

Table A 2: Descriptive Statistics of the Variables Used for Estimation of the Hedonic Property Value model: Location Kolkata

	Rent (Rs/month) (Y_1)	Covered area (Sq ft.) (X_1)	Number of rooms (X_2)	Indoor sanitation Index (X_3)	Distance from Business Centre (Km) (X_4)	Distance from National Highway (Km) (X_5)
Mean	3902.831	1169.304	4.324751	4.889535	5.157973	1.137949
Std. Dev.	4288.262	1284.462	3.041145	1.356095	6.775391	1.062752
Observations	1204	1204	1204	1204	1204	1204

	Distance from Slum (Km) (X_6)	Distance from Industry (Km) (X_7)	Dummy for Nearby Slums (X_8)	Dummy for Business Community (X_9)	Perception of Air Quality Index (X_{10})	Index for Adequacy of Green Cover (X_{11})
Mean	0.330133	0.627816	0.553156	2.095515	1.830565	0.347176
Std. Dev.	1.167176	0.789318	0.497373	0.761728	0.785062	0.483201
Observation	1204	1204	1204	1204	1204	1204

	Perception about drinking water (X_{12})	SPM (X_{13})	SO_2 (X_{14})	NO_2 (X_{15})	Water Supply (Hours / day) (X_{16})	Distance from Nearest Shopping Centre (Km) (X_{17})
Mean	2.182724	331.3123	8.892027	123.3310	8.711379	1.243937
Std. Dev.	0.807179	83.98949	2.018197	37.08074	6.359156	1.309642
Observation	1204	1204	1204	1204	1204	1204

	Education Index (Years) (X_{18})	Gross annual Family Income (Rs) (X_{19})	SPM*SPM (X_{20})	
Mean	14.28763	158930.1	116816.2	
Std. Dev.	3.165503	102890.3	53862.82	
Observation	1204	1204	1204	

Table A 3: Descriptive Statistics of the Variables Used for Estimation of the Hedonic Property Value Model: Location Pooled data of Delhi and Kolkata

	Rent (Rs/month) (Y_1)	Covered area (Sq yards) (X_1)	Number of rooms (X_2)	Indoor sanitation Index (X_3)	Distance from Business Centre (Km) (X_4)	Distance from National Highway (Km) (X_5)
Mean	6546.224	679.1058	4.194072	4.677541	4.973521	1.782558
Std. Dev.	10354.50	1146.499	2.783644	1.275187	5.904172	2.033789
Observations	2391	2391	2391	2391	2391	2391

	Distance from Slum (Km) (X_6)	Distance from Industry (Km) (X_7)	Dummy for Nearby Slums (X_8)	Dummy for Business Community (X_9)	Perception of Air Quality Index (X_{10})	Index for Adequacy of Green Cover (X_{11})
Mean	0.957724	0.976673	0.560484	1.328437	1.976979	0.486410
Std. Dev.	1.349522	1.139571	0.496428	1.009871	0.727994	0.548683
Observations	2391	2391	2391	2391	2391	2391

	Perception about drinking water (X_{12})	SPM (X_{13})	SO_2 (X_{14})	NO_2 (X_{15})	Water Supply (Hours / day) (X_{16})	Distance from Nearest Shopping Centre (Km) (X_{17})
Mean	2.147190	349.0961	10.81923	82.08902	7.376280	2.533180
Std. Dev.	0.968021	86.66497	3.770856	52.22872	6.330675	2.637017
Observations	2391	2391	2391	2391	2391	2391

	Education Index (Years) (X_{18})	Gross annual Family Income (Rs) (X_{19})	SPM*SPM (X_{20})	Dummy Delhi=1, Kolkata=0 (X_{23})	
Mean	13.76080	167671.7	129375.9	0.477474	
Std. Dev.	3.790868	115361.6	63181.19	0.499593	
Observations	2391	2391	2391	2391	

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