Economic Growth and the Environment: A Household Perspective from Cooking Fuel Choices and Indoor Air Pollution*

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Abstract

This paper examines the relationship between economic growth and the environment from a household perspective through fuel-use decisions. Because household fuel choices directly influence the level of indoor air quality that can be treated as a private good, studying household fuel-use decisions allows us to empirically assess household preference towards the environment and determine how it evolves with increased income. Such an assessment is important for a better understanding of the effect of economic growth on the environment in certain cases such as a small open economy with perfect environmental policies. This study has two major differences from the previous similar studies. First, in terms of the theoretical model, instead of using a simple static model, we adopt a dynamic optimization model in an open economy setting. Second, in terms of empirical analysis, instead of using indirect air quality measurements, we use household data from India with directly measured indoor air quality in terms of PM 2.5 concentrations. In contrast to previous findings, we find that there is no inverted-U relationship between indoor air pollution and income; instead, pollution levels decrease monotonically as income increases.

JEL codes: D11, Q53, Q56, O12

* These results are based on the Health, Environment, and Economic Development survey. This survey was jointly organized by researchers at the University of Maryland, the University of California at Berkeley, the World Bank, the Energy Research Institute, Sri Ramachandra Medical College, and the National Council of Applied Economic Research. The data collection was funded by grants R21AG02402101, R01HD041455 and R01HD046166 from the National Institutes of Health to University of Maryland. We would like to thank Maureen Cropper, Kenneth Leonard, Ramon Lopez, and Richard Just for valuable comments. The authors are responsible for all errors and omissions.

I Introduction

About half of the world's population, over 3 billion people, still rely on traditional biomass fuel such as wood, dung, and crop residue for domestic energy needs. Indoor air pollution (IAP) caused by burning traditional biomass fuel has been a major environmental and public health hazard for these people. Global estimates show that about 2.5 million deaths each year result from indoor exposure to particulate matter in rural and urban areas in developing countries, representing 4-5% of the 50-60 million global deaths that occur annually (Bruce et al., 2002). However, the transition to cleaner fuels among the poor has been slow and there is evidence that reliance on biomass is increasing in some parts of the world.

Indoor air quality is a special environmental good that can be treated as a private good. Household fuel choices that directly influence the level of indoor air quality reflect household preference towards the environment. Assessing how household fuel choices and indoor air quality change with income provides an opportunity for a better understanding of the effect of economic growth on the environment in certain cases such as a small open economy with perfect environmental policies.

There has been wide-spread interest in finding out the relationship between economic growth and the environment over the last decade. Is deterioration of environment a prerequisite for economic growth or is sustainable economic growth possible without running into resource constraints or despoiling the environment beyond repair? Early concerns were that economic growth (production and consumption) requires larger inputs of energy and material, which will generate larger quantities of waste byproducts. Despite initial rising incomes, increased extraction of natural resources and concentration of pollutants would overwhelm the carrying capacity of the biosphere and result in the degradation of environmental quality. Furthermore, degradation of resources and the environment would eventually put economic activity itself at risk (Jansson el al. 1994, Panayotou 2000).

Some argue that with higher income, people will care more about environment quality. Thus, there will be increased demand for goods and services that are less pollution-intensive. Furthermore, increases in income will increase the ability of governments to afford costly investments in environmental protection. In other words, being rich is the way to improve the environment (Beckerman 1992).

A more popular argument suggests an inverted-U relationship between pollution and income, which means that pollution will first increase, but subsequently decline if growth proceeds far enough. This relationship is also known as the environmental Kuznets curves (EKC). The hypothesis is that at low levels of development, as agriculture and resource extraction intensifies and industrialization takes off, both resource depletion and pollution generation would accelerate; at higher levels of development, structural change towards information and technology-based industries and increased demand for environmental quality would result in declination of environmental degradation (Panayotou 2000).

A number of empirical studies have examined the relationship between economic growth (often measured as per capita income) and environment quality since the seminal work of Grossman and Krueger (1993). For some measures of air quality such as SO_2

concentrations, research (Selden and Song, 1994; Grossman and Krueger, 1995) found an inverted-U relationship between pollution and income per capita. For other pollutants such as contaminated drinking water, Shafik and Banyopadhyay (1992) and Grossman and Krueger (1995) found pollution declines monotonically with income per capita; while for others such as carbon emissions, pollution tends to rise with income per capita. Unfortunately, these empirical studies were not well guided by theories, which made interpretation difficult.

This paper examines the relationship between economic growth and the environment from a household perspective through fuel-use decisions. How a small open economy values its environmental quality can be mirrored in how a household values his indoor air quality, assuming the small open economy does not consider environmental externalities to other economies. In a small open economy, a social planner makes the optimal environmental policies (such as pollution tax) to reflect environmental externalities to all sectors and individuals in the economy. While a household also fully internalizes the effect of indoor air pollution when selecting cooking fuels, it can indeed be treated as a special case of a small open economy. Thus, by investigating the relationship between income and indoor air quality in a household, we can infer the relationship between growth and the environment in a small open economy with perfect environmental policies.

This approach is similar to Chaudhuri and Pfaff's study (2003) on household fuel-choices and indoor air quality using household data from Pakistan. However, our study has two major differences. First, in terms of the theoretical model, instead of using a simple static household production model, we adopt a dynamic optimization model in an open economy setting. Second, in terms of empirical analysis, we use household data from India with directly measured indoor air quality in terms of PM 2.5 concentrations. Because the data set from Pakistan does not include indoor air quality data, Chaudhuri and Pfaff's estimation used partially simulated data based on the observed fuel choices. In contrast to Chaudhuri and Pfaff's findings, we find that there is no inverted-U relationship between indoor air pollution (IAP) and income; instead, pollution levels decrease monotonically as income increases.

This paper is organized as follows. Section II develops a theoretical model that adopts a dynamic utility optimization framework in an open economy. Section III details the econometric strategy, data sources, and then presents and discusses empirical results. Section IV concludes.

II Theoretical Model

Almost all theoretical models of the interaction of economic growth and the environment are macroeconomic models. These can be divided into four major categories: (A) optimal growth models, (B) models in which the environment is a factor of production, (C) endogenous growth models, and (D) other macroeconomic models such as an overlapping generation model and a two-country general equilibrium model of growth and the environment in the presence of trade (Panayotou 2000). Most of type A and type D models support the EKC. Type B models emphasize that property rights are decisive in determining whether environmental degradation eventually declines with growth. Type C models suggest pollution standards should be tightened with economic growth.

Chaudhuri and Pfaff (2003) used a simple static household production model and indicated that the relationship between household income and environmental quality may be non-monotonic. The study showed that the household's optimal choice of fuel would be such that at low levels of income only the dirty fuel is used; at intermediate levels of income, both fuels are used with the share of the cleaner fuel rising with income; and at high levels of income, only clean fuel is used. Once a household specializes completely in the clean fuel, subsequent increases in income can only lead to a deterioration of air quality. Chaudhuri and Pfaff (2003) implicitly assume that there is no food market available, which means that households cannot buy ready-to-eat food and have to cook for themselves.

We adopt a dynamic model of pollution in an open economy developed by Lopez (2007) to model household fuel choices. Since both production and consumption of a household are very small when compared to the market, a household can be treated as a special case of a small open economy. We assume the market is perfectly developed. A household can trade food and all other products (including input factors) on the market and their prices are exogenously determined.

We assume a household consumes two types of goods, one is food (denoted as f) and the other is the composite good (denoted as h), and they have constant elasticity of substitution. Food can be produced either by clean fuel or by dirty fuel and can also be traded on the market. We denote food produced by clean fuel as f_c and by dirty fuel as f_d and food traded on the market as f_m. They are all perfect substitutes and their relative price to good h is p. Food traded on the market can be either produced by dirty fuel or clean fuel. Households would not care what type of fuel is used when they buy food on the market. When food is produced by dirty fuel, the cooking process generates indoor air pollution which is denoted as *x* and generates disutility to the household. In addition, we denote the household's discount rate as ρ . Thus, we assume that the household has the following dynamic optimization problem.

$$Max \int_0^\infty \left\{ \frac{\varepsilon}{\varepsilon - 1} (f^\alpha h^{1-\alpha})^{\frac{\varepsilon-1}{\varepsilon}} - v(x) \right\} e^{-\rho t} dt \qquad (0 < \alpha < 1, \text{and } \varepsilon > 0) \tag{1}$$

Subject to

$$\dot{k} = A(k - k_c - k_d) + pF(k_c) + pG(k_d, x) - pf_c - pf_d - pf_m - h - \delta k \tag{2}$$

$$k(0) = \bar{k}_0 \tag{3}$$

where

$$f = f_c + f_d + f_m \tag{4}$$

$$v(x) = x^{1+\eta} \qquad (\eta > 0) \tag{5}$$

The factor *k* can be treated as a composite of all factors of production such as capital and labor and we assume it has a constant depreciate rate δ . The level of the initial stock *k* is given. The household can choose an optimal investment rate which will cause the future of stock of *k* to change but it cannot affect the current level of such stock. The choice of the level of *k* is determined by (1) the marginal returns obtained by holding one unit of k for one period of time and (2) the cost of holding such unit of capital for one period of time. This cost includes the opportunity cost of keeping *k* instead of consuming it, which is ρ , and the depreciation that *k* will suffer during the period, which is δ .

The household also needs to allocate k into different sectors to ensure k is in the best use. $A(k-k_c-k_d)$, $F(k_c)$, and $G(k_d,x)$ are production functions for good h, food produced by clean fuel f_c, and food produced by dirty fuel f_d, respectively. $F(k_c)$ and $G(k_d,x)$ are constant returns to scale functions with $F'(k_c)>0$, $F''(k_c)<0$, $G_i(k_d,x)>0$ $(i=1,2)$, $G_{ii}(k_d,x)<0$, and $G_{ij}(k_d,x)>0$ $(i \neq j)$. From equation (5), we can see that $\frac{v''x}{v'} = \eta$, which means that $v(x)$ is increasing and convex in the level of pollution.

The Hamiltonian to be maximized is

$$H = \frac{\varepsilon}{\varepsilon - 1}(f^{\alpha} h^{1-\alpha})^{\frac{\varepsilon-1}{\varepsilon}} - v(x) + \lambda\left[A(k - k_c - k_d) + pF(k_c) + pG(k_d, x) - pf_c - pf_d - pf_m - h - \delta k\right] \tag{6}$$

First order conditions are

$$\frac{\partial H}{\partial f_c} = \frac{\partial H}{\partial f_d} = \frac{\partial H}{\partial f_m} = \alpha(f^{\alpha} h^{1-\alpha})^{-\frac{1}{\varepsilon}} f^{\alpha-1} h^{1-\alpha} - \lambda p = 0 \tag{7}$$

$$\frac{\partial H}{\partial h} = (1-\alpha)(f^{\alpha} h^{1-\alpha})^{-\frac{1}{\varepsilon}} f^{\alpha} h^{-\alpha} - \lambda = 0 \tag{8}$$

$$\frac{\partial H}{\partial k_c} = \lambda\left(-A + pF'(k_c)\right) = 0 \Rightarrow pF'(k_c) = A \tag{9}$$

$$\frac{\partial H}{\partial k_d} = \lambda\left(-A + pG_1(k_d, x)\right) = 0 \Rightarrow pG_1(k_d, x) = A \tag{10}$$

$$\frac{\partial H}{\partial x} = -v'(x) + \lambda\left(pG_2(k_d, x)\right) = 0 \Rightarrow pG_2(k_d, x) = \frac{v'(x)}{\lambda} \tag{11}$$

$$-\frac{\partial H}{\partial k} = \lambda(A - \delta) = \dot{\lambda} - \rho\lambda \Rightarrow \frac{\dot{\lambda}}{\lambda} = \rho + \delta - A \tag{12}$$

Conditions (7) and (8) imply

$$f = \frac{\alpha}{(1-\alpha)p} h \tag{13}$$

Substituting (13) in (7), we get

$$\alpha \left(\frac{\alpha}{(1-\alpha)p} \right)^{-\frac{\alpha}{\varepsilon}+\alpha-1} h^{-\frac{1}{\varepsilon}} = \lambda \tag{14}$$

Defining

$$B \equiv \alpha \left(\frac{\alpha}{(1-\alpha)p} \right)^{-\frac{\alpha}{\varepsilon}+\alpha-1} \tag{15}$$

we get

$$B(p) h^{-\frac{1}{\varepsilon}} = \lambda \tag{14'}$$

From (12), we see that $\hat{\lambda} = \frac{\dot{\lambda}}{\lambda} < 0$ if $A > \rho + \delta$. So, λ falls at a constant rate if production for h is sufficiently productive.

From (13) and (14') we have

$$\frac{\dot{f}}{f} = \frac{\dot{h}}{h} = -\varepsilon \frac{\dot{\lambda}}{\lambda} = \varepsilon(A - \rho - \delta) \tag{16}$$

which is also constant. So, there is no transitional dynamics.

Equations (9) and (10) show that both $F'(k_c)$ and $G_1(k_d, x)$ are constant. Equation (10) implies that k_c is constant at the optimal level. Because $G(k_d,x)$ is homogeneous of degree one, equation (10) implies that there is a unique $\left(\frac{k_d}{x}\right)^*$ optimal ratio which is fixed as long as A and p are constant. Thus, $G_2\left(\left(\frac{k_d}{x}\right)^*, 1\right)$ is also constant. Using equation (11), this implies that the shadow price of pollution $\frac{v'(x)}{\lambda}$ must also be fixed over time. Taking total differential to $\frac{v'(x)}{\lambda}$ with respect to *t* and making the resulting expression equal to zero, we get

$$\frac{xv''(x)}{v'(x)}\frac{\dot{x}}{x} = \frac{\dot{\lambda}}{\lambda} = \rho + \delta - A \qquad (17)$$

Substituting equation (5) in (17), we get

$$\hat{x} = \frac{\dot{x}}{x} = -\frac{1}{\eta}(A - \rho - \delta) < 0 \qquad (18)$$

Because indoor air pollution is a private good, it is reasonable to assume that households completely internalize its externalities. Therefore, as equation (18) implies, as long as wealth increases, households will constantly reduce IAP over time. Intuitively, as households become wealthier, the value of shadow price λ falls, which causes the pollution price $\frac{v'(x)}{\lambda}$ to increase. In other words, pollution becomes more costly as households become wealthier. This causes pollution *x* to fall which in turn induces $\left(\frac{k_d}{x}\right)$ to temporarily increase. Then $\left(\frac{k_d}{x}\right) > \left(\frac{k_d}{x}\right)^*$ implies that $pG_1\left(\left(\frac{k_d}{x}\right)^*, 1\right) < A$. This means that the marginal product of conventional factors of production *k* in production of f_d (food produced by dirty fuels) becomes less than the marginal product of the same factors in production of f_c and *h.* Thus, to ensure *k* is in the best use, the households will switch conventional factors from production of f_d to production of f_c and *h.* This process continues until $\left(\frac{k_d}{x}\right) = \left(\frac{k_d}{x}\right)^*$. Because f_c and f_m are perfect substitutes for f_d, this means that households will eventually stop using dirty fuels for food production as income continues increasing. Therefore, instead of observing the EKC, an inverted U-shape curve, we should observe a monotonic decreasing curve.

III Empirical Analysis

The data for this study comes from a social science and environmental health survey entitled Health, Environment, and Economic Development (HEED). The HEED survey was jointly organized by researchers at the University of Maryland, the University of California at Berkeley, the World Bank, the Energy Research Institute, Sri Ramachandra Medical College, and the National Council of Applied Economic Research. The survey sample is a more diverse sample of households than found in earlier studies (Vanneman et al., 2006). It involves about 620 households with 3,000 individuals from two districts in each of four geographically, culturally, and economically disparate states. Two villages and one urban neighborhood were sampled in each district. Both social science and physical measures of indoor air pollution and other health measures such as lung capacity were collected. In particular, the HEED survey includes a detailed section on household fuel use and cooking conditions and a section on 24-hour minute-by-minute direct measures of pollution levels for both kitchen and living areas.

The advantage of using direct IAP measures instead of using indirect measures such as fuel choices and housing characteristics is that the latter cannot capture the complexity of emission patterns and thus may result in biased estimates. The research finds that emissions from biomass stoves vary greatly over short time intervals and these fluctuations relate to combustion characteristics (such as energy density, combustion temperature, and air flow) and cooking behavior. For example, the emission peaks occur when fuel is added or removed, the stove is lit, the cooking pot is placed on or removed from the fire, or food is stirred. In addition, pollution concentrations are found to exhibit a pronounced spatial gradient rather than instantaneous mixing (Ezzati and Kammen, 2002).

Among biomass smoke pollutants, particular matter less than 2.5 μm (PM 2.5) in diameter are considered the most harmful to health because they are small enough to be inhaled and transported deep into the lungs (WHO, 2006). For biomass smoke, the modal size of particles is between 0.2 and 0.4 μm, and 80 to 95% of particles are smaller than 2.5 μm (Kleeman et al., 1999). In this study, the concentration of PM 2.5 in milligrams per cubic meter (mg/m^3) is used as the indicator of indoor air pollution.

Because we cannot derive a closed-form analytical expression for the pollution and income using the dynamic optimization model detailed in Section II, we estimate the following two reduced-form equations.

$$Y = I\beta_1 + X'\gamma + \varepsilon \tag{19}$$

$$Y = I\beta_1 + I^2\beta_2 + I^3\beta_3 + X'\gamma + \varepsilon \tag{20}$$

where Y is a measure of indoor air pollution, I is household wealth level, and X is a vector of other covariates, and ε is an error term. To reflect the different exposure patterns, we select the mean and the 95th percentage of PM 2.5 concentrations in kitchen as the dependent variables in this study, respectively. Since income is usually more fluctuated than expenditure, we use household annual per-capita expenditure as the indicator for wealth level. The first specification provides a benchmark and the second includes a polynomial in I to allow for possible non-linearities. We use the cubic specification because experimentation with unrestricted dummy variables suggests that the cubic specification is flexible enough to describe the varied relationship between pollution and income (Grossman and Krueger, 1995). Other covariates include household size, urban/rural dummy, health belief dummy (equals to 1 if a household believes that smoke is harmful), temperature, humidity, and state and caste dummies.

Table 1 presents summary statistics of key variables. Note that because very few households have a mean of PM2.5 concentrations greater than 5 mg/m^3 as shown in Figure 1, we remove these outliers in our sample.

The major disutility from IAP comes from its health impacts, including respiratory diseases in particular. The World Health Organization estimates that exposure to indoor air pollution (IAP) causes about 500,000 premature deaths and 500 million incidences of illness among women and children in India each year, which amounts to 30 percent of the global disease burden from this risk factor in the developing world and makes IAP one of the top preventable health risks in India (ESMAP, 2002). Our theoretical model in Section II assumes that households understand IAP's health impacts and fully internalize such impacts when making decisions. However, such assumption may not completely reflect reality. As the survey data shows, almost 20% of households are not aware of health damage from IAP, which means that they may not care much about indoor air quality. Thus, whether understand IAP's health impacts can play a critical role in the relationship between IAP and income. However, knowledge on IAP's health impacts is potentially correlated with income. If it is true, including both income and the health belief variable will result in biased estimates. Figure 2 shows percentage of households who are not aware of IAP's health impacts by ten income categories. Although the data does not reveal a systematic correlation between income and knowledge on IAP, we include an alternative estimation using the sample excluding households who are not aware of IAP's health impacts.

Being in urban areas is another factor that could affect the pollution-income relationship. The most important reason that keeps households using traditional biomass (dirty fuel) for cooking is that it is cheaper than modern fuels and sometimes can be collected for free. However, costs to obtain traditional biomass in urban areas can be substantially higher than those in rural areas. Thus, with the same income level, households in urban areas have more incentives to switch to clean fuels to achieve better indoor air quality.

Household size is potentially another important factor determining the pollution-income relationship. Chaudhuri and Pfaff (2003) detailed this factor in their paper. Since they use per capita use of fuels as the dependent variable, household size appears to be a very important influence on fuel-choice and fuel-use decisions. They conclude that controlling for per-capita household expenditure, larger households are less likely to use traditional fuels and also use lower quantities per-capita when they do use it. The problem with this analysis is that indoor air pollution is mainly determined by the total fuel use, not by per capita use of fuels. Although there may be economies of scale in cooking, an increase in household size will increase the total fuel used and the cooking time spent, which will directly influence indoor air quality. Economies of scale in fuel use may also play a role in switching to modern fuels because of lower per-service-unit costs of modern fuels and greater benefits of improving indoor air quality. Since these two effects are in opposite directions, it is hard to predict the overall effect of household size on the pollution-income relationship.

Regression results are presented in Table 2 and Table 3. The dependent variable in Table 2 is the mean of PM 2.5 concentrations in kitchen and in Table 3 is the 95th percentage of PM 2.5 concentrations in kitchen. Columns (1) and (2) use linear specifications and Columns (3) and (4) use cubic specifications. To ensure that health knowledge is not a disturbing factor, Columns (1) and (3) uses the sample excluding those households who are not aware of IAP health impacts. Column (3) is our preferred specification. For comparison, Column (2) and (4) include all households and control for health belief.

As we expected, health belief is a statistically significant factor in determining IAP levels. Because income and health belief are not systematically correlated as shown in Figure 2, the estimated coefficients for income in Columns (1) and (3) are only slightly different from the corresponding ones in Columns (2) and (4). The urban dummy shows a negative impact on IAP concentrations as we expected and is statistically significant at the 1% level in all regressions. In terms of household size, it shows a positive impact on IAP concentrations, but is not statistically significant in Column (3). This implies that the increased fuel use and cooking time caused by an increase in household size may dominate the overall effect, but not significantly.

Because estimation results for the mean and the 95th percentile of PM 2.5 concentrations are very similar, we only illustrate the results for mean of PM 2.5 concentrations. Figure 3 shows the scatter plot of the relationship between annual per capita expenditure and mean of PM 2.5 concentrations in kitchen using the raw data and Figure 4 presents the shape of the predicted relationship using the estimates in Column (3) in Table 2. The empirical estimations confirm our theoretical prediction that indoor air pollution decreases monotonically as income increases.

IV Conclusion

Because indoor air pollution is a private good, it provides a window on households' valuation of environmental quality. This paper examines the relationship between growth and the environment from a household perspective on how cooking fuel choices and indoor air pollution change as household income increases. We adopt a dynamic model on pollution in an open economy to model household fuel choices. Contrary to the static household production model used in Chaudhuri and Pfaff (2003), we find that instead of observing the EKC, an inverted U-shape curve, we should observe a monotonic decreasing curve. Our empirical evidence using the measured IAP levels is consistent with the implications of our theoretical model.

Therefore, we conclude that in the case of a small open economy with perfect environmental policies, pollution decreases as economy grows. Note that this conclusion does not apply to closed economies (most large countries) where prices are endogenously determined. In addition, our findings imply that the problem of indoor air pollution in developing countries will not be solved unless their economies are sufficiently developed.

Table 1. Summary Statistics

Variables	Mean	Std. Dev.	Min	Max
Mean of PM2.5 concentrations in Kitchen (mg/m3)	0.545	0.711	0.017	3.835
95th percentage of PM2.5 concentrations in Kitchen (mg/m3)	2.069	3.141	0.015	21.088
Household expenditure: annual (Rs)	54991.240	52505.570	0	730312
Per-capita expenditure: annual (Rs)	11100.280	8015.776	0	58801
Urban dummy	0.313	0.464	0	1
Health belief dummy: smoke is harmful	0.837	0.370	0	1
Household size	5.106	2.154	1.000	15.000
Median temperature (Celsius)	20.696	4.590	9.430	30.490
Median humidity	64.160	10.299	31.000	87.500

Table 2. Regression Results for Mean of PM2.5 Concentrations in Kitchen

Dependent Variable: Mean of PM 2.5 Concentrations in Kitchen (mg/m3)	Linear Specification		Cubic Specification	
	(1)	(2)	(3)	(4)
Per-capita expenditure: annual (Rs)	-1.262e-05**	-1.247e-05**	-5.341e-05*	-6.350e-05**
	[2.909]	[3.230]	[1.982]	[2.589]
Per-capita expenditure squared			1.597E-09	2.111e-09+
			[1.187]	[1.777]
Per-capita expenditure cubed			-1.471E-14	-2.164E-14
			[0.816]	[1.416]
Urban dummy	-0.280**	-0.275**	-0.267**	-0.268**
	[3.930]	[4.071]	[3.741]	[3.973]
Health belief dummy: smoke is harmful		-0.201*		-0.195*
		[2.436]		[2.379]
Household size	0.030+	0.035*	0.025	0.030*
	[1.918]	[2.412]	[1.565]	[2.028]
Median temperature (Celsius)	0.044**	0.038**	0.047**	0.042**
	[3.859]	[3.551]	[4.119]	[3.888]
Median humidity	-0.006	-0.007+	-0.006	-0.007+
	[1.611]	[1.888]	[1.503]	[1.855]
West Bengal	-0.347*	-0.330*	-0.397**	-0.380**
	[2.486]	[2.427]	[2.811]	[2.777]
Madhya Pradesh	-0.337**	-0.284**	-0.367**	-0.312**
	[3.049]	[2.625]	[3.306]	[2.881]
Tamil Nadu	-0.855**	-0.839**	-0.918**	-0.904**
	[5.134]	[5.181]	[5.428]	[5.514]
Brahmin	-0.416*	-0.302+	-0.406*	-0.293+
	[2.512]	[1.964]	[2.457]	[1.911]
OBC	-0.092	0.061	-0.093	0.053
	[0.662]	[0.481]	[0.672]	[0.414]
Scheduled Castes	-0.123	0.002	-0.125	-0.01
	[1.006]	[0.017]	[1.027]	[0.095]
Scheduled Tribes	-0.146	-0.083	-0.151	-0.101
	[0.982]	[0.604]	[1.021]	[0.742]
Muslim	-0.159	-0.094	-0.165	-0.111
	[0.760]	[0.502]	[0.789]	[0.594]
Other-Sikh,Christian,Jain	0.251	0.231	0.278	0.264
	[0.809]	[0.785]	[0.898]	[0.903]
Constant	0.55	0.755*	0.737+	1.000**
	[1.468]	[2.091]	[1.902]	[2.674]
Observations	420	502	420	502
R-squared	0.176	0.18	0.185	0.190

Absolute value of t statistics in brackets
+ significant at 10%; * significant at 5%; ** significant at 1%

Table 3 Regression Results for 95th Percentile of PM2.5 Concentrations in Kitchen

Dependent Variable: 95th Percentile of PM 2.5 Concentrations in Kitchen (mg/m3)	Linear Specification		Cubic Specification	
	(1)	(2)	(3)	(4)
Per-capita expenditure: annual (Rs)	-5.089e-05**	-6.184e-05**	-2.009e-04+	-2.898e-04**
	[2.695]	[3.669]	[1.712]	[2.712]
Per-capita expenditure squared			5.37E-09	8.714e-09+
			[0.916]	[1.683]
Per-capita expenditure cubed			-4.15E-14	-7.973E-14
			[0.528]	[1.198]
Urban dummy	-1.356**	-1.141**	-1.298**	-1.111**
	[4.376]	[3.865]	[4.178]	[3.781]
Health belief dummy: smoke is harmful		-0.822*	0.00E+00	-0.789*
		[2.285]	0.00E+00	[2.204]
Household size	0.117+	0.152*	9.30E-02	0.121+
	[1.690]	[2.377]	[1.318]	[1.884]
Median temperature (Celsius)	0.168**	0.136**	0.182**	0.156**
	[3.374]	[2.877]	[3.626]	[3.284]
Median humidity	-0.044**	-0.041**	-0.042*	-0.041*
	[2.620]	[2.587]	[2.521]	[2.557]
West Bengal	-2.203**	-1.862**	-2.420**	-2.135**
	[3.627]	[3.142]	[3.931]	[3.579]
Madhya Pradesh	-2.043**	-1.674**	-2.177**	-1.824**
	[4.251]	[3.545]	[4.497]	[3.863]
Tamil Nadu	-4.085**	-3.769**	-4.361**	-4.132**
	[5.636]	[5.333]	[5.922]	[5.784]
Brahmin	-2.525**	-1.916**	-2.481**	-1.875**
	[3.499]	[2.855]	[3.444]	[2.812]
OBC	-1.097+	-0.343	-1.109+	-0.412
	[1.820]	[0.618]	[1.841]	[0.744]
Scheduled Castes	-0.771	-0.268	-7.84E-01	-0.338
	[1.453]	[0.562]	[1.480]	[0.713]
Scheduled Tribes	-1.338*	-1.010+	-1.368*	-1.124+
	[2.072]	[1.693]	[2.121]	[1.890]
Muslim	-1.347	-0.884	-1.37E+00	-0.986
	[1.478]	[1.080]	[1.509]	[1.211]
Other-Sikh,Christian,Jain	1.451	1.157	1.58E+00	1.339
	[1.076]	[0.902]	[1.170]	[1.049]
Constant	4.611**	5.053**	5.339**	6.229**
	[2.829]	[3.207]	[3.165]	[3.824]
Observations	420	502	420	502
R-squared	0.213	0.198	0.22	0.211

Absolute value of t statistics in brackets
+ significant at 10%; * significant at 5%; ** significant at 1%

Figure 1. Distribution of Mean of PM 2.5 Concentrations in Kitchen

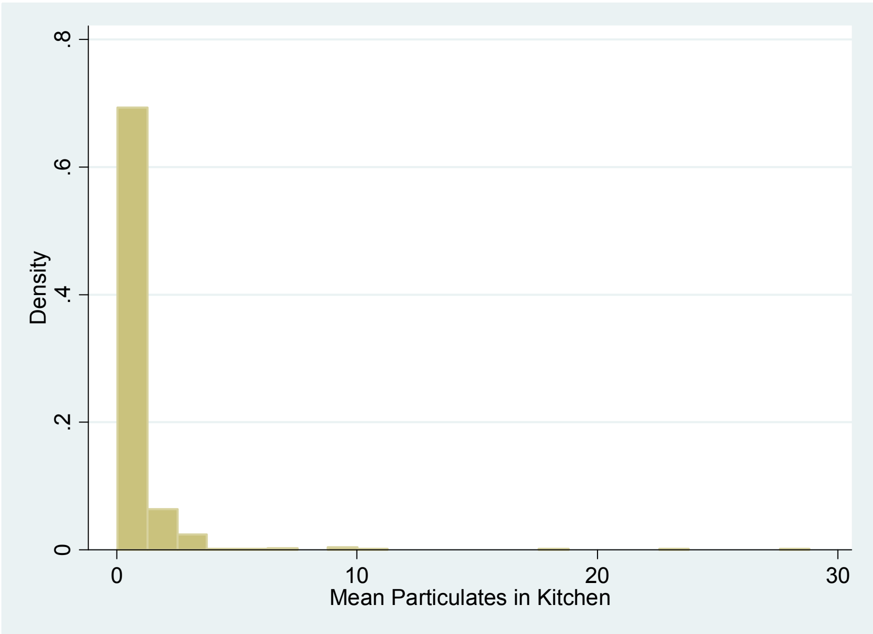


Figure 2. Percentage of Households Who Are not Aware of IAP's Health Impacts, by Ten Annual Per Capita Expenditure Categories (poor to rich)

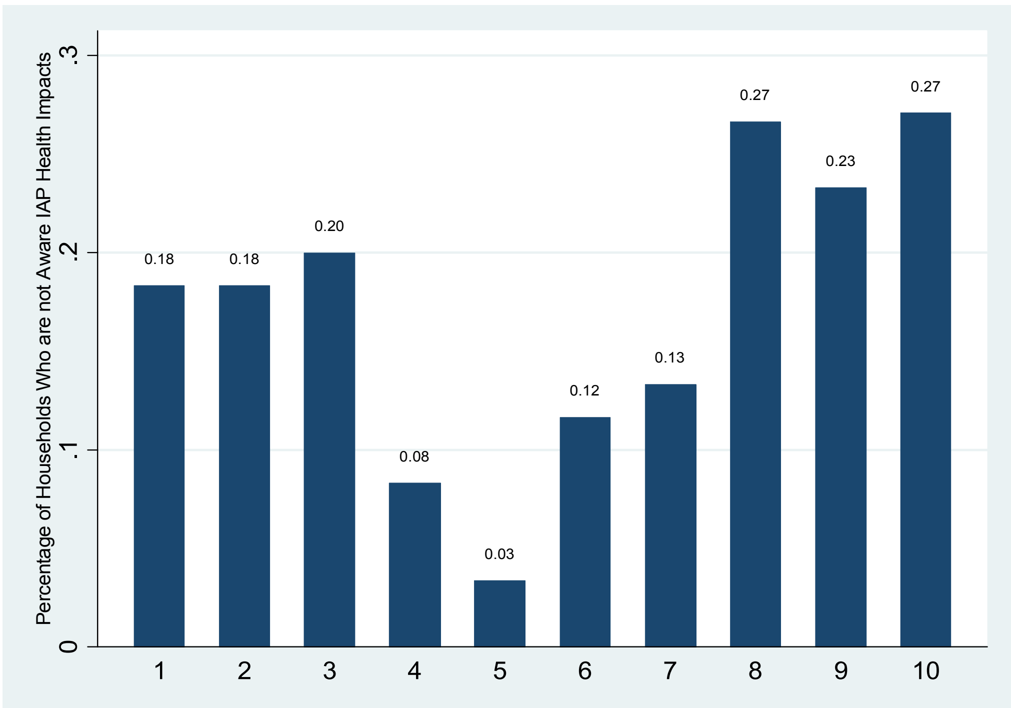


Figure 3. Scatter Plot of the Relationship between Annual Per Capita Expenditure and Mean of PM 2.5 Concentrations in Kitchen

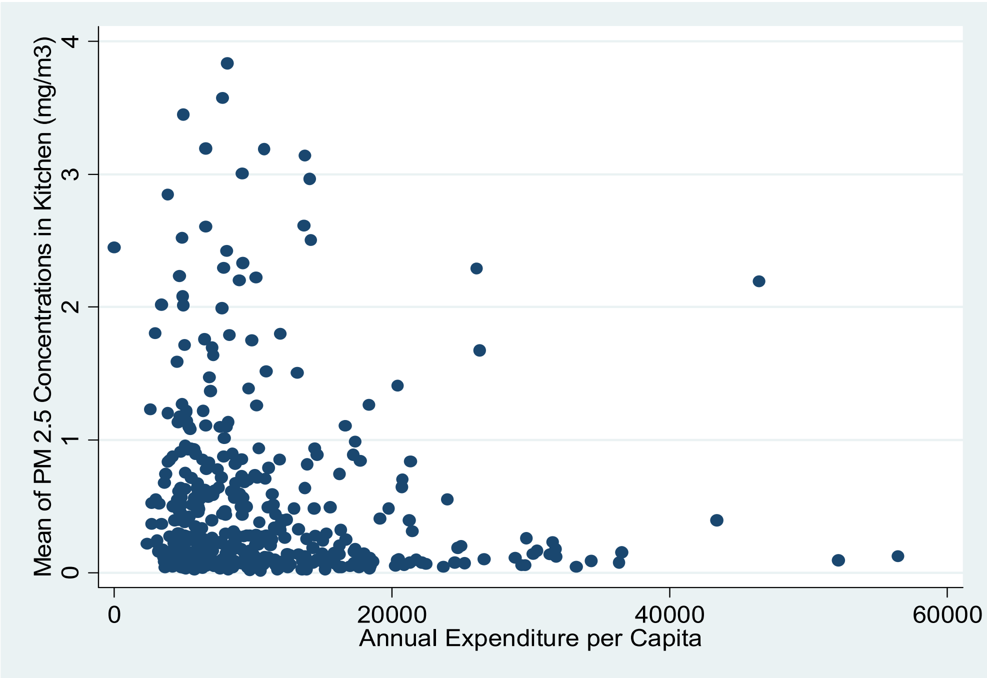
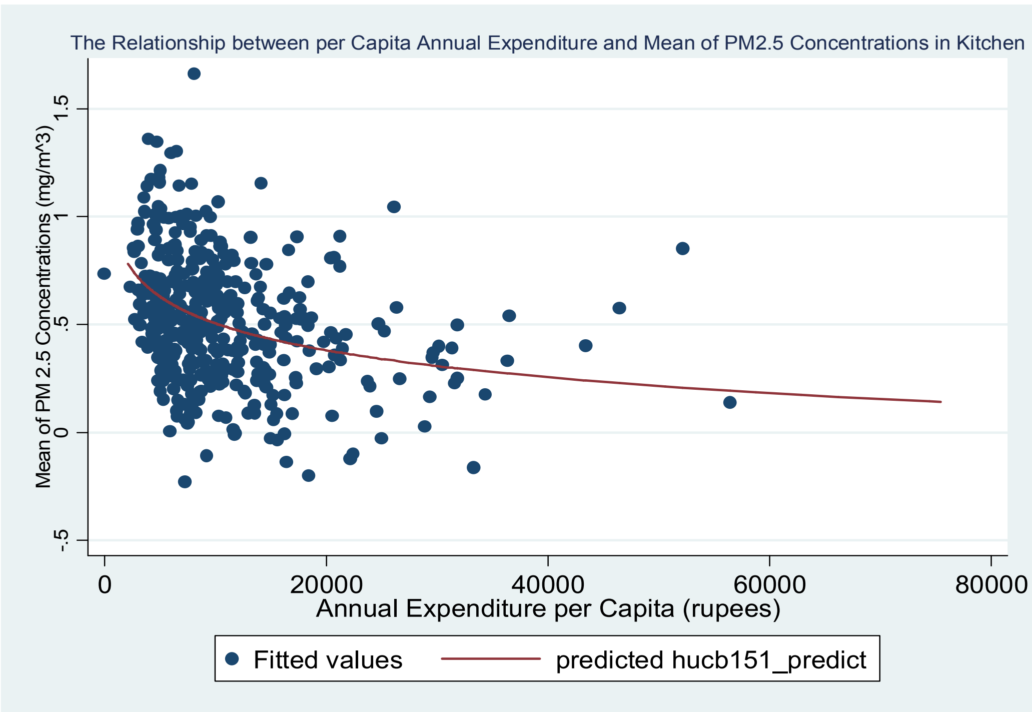


Figure 4. Estimated Relationship between Annual Per Capita Expenditure and Mean of PM 2.5 Concentrations in Kitchen



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