DOES ENVIRONMENTAL KUZNET'S CURVE EXIST FOR INDOOR AIR POLLUTION?
EVIDENCE FROM INDIAN HOUSEHOLD LEVEL DATA

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Key Words: Indoor Air Pollution, Environmental Kuznets Curve, Energy Policy.

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ABSTRACT

Existence of Environmental Kuznet's Curve (EKC) is an empirical issue to analyze as evidence from the literature has been mixed. This study focuses on indoor air pollution generated from the use of fuels for cooking services to check for validity of EKC. Using household level data from three rounds of National Sample Survey over the period from 1983 to 2000, the study estimates aggregate 'dirty' and 'clean' fuel Engle curves. The study also estimates pollution-income relationship and uses the predicted indoor pollution to simulate EKC. The results show validation of EKC hypothesis, especially for the data corresponding to rural households. In contrast, indoor pollution shows declining trend in 1990s for the urban households. The spatial and temporal representations of pollution-income relationship presented in this study highlight stark difference between the rural and urban households along with their rate of progress towards 'clean' fuels and provide insights on potential policy responses that could enable faster transition of rural households towards 'cleaner' fuels.

Does Environmental Kuznet's Curve Exist for Indoor Air Pollution? Evidence from Indian Household Level Data

1.0 Introduction

The observation that pollution increases and then decreases with economic growth has come to be known as environmental Kuznets curve hypothesis and in the past one decade there has been considerable interest among researchers and policy makers on existence of environmental Kuznets curve (hereafter EKC), theoretical foundations of EKC, and its policy implications. Rich volume of literature that has developed ever since the publication of original studies by Grossman and Krueger (1995), Shafik and Bandyopadhyay (1992), and Panayotou (1993) has focused on all these aspects[1]. While most of the studies have focused on aggregate macro level data and explanations to support EKC hypothesis, some recent studies started looking at micro level data in an attempt to gain better understanding of the route through which the EKC could arise. The present study is a contribution in that direction with focus on indoor air pollution generated through cooking fuel consumption by Indian households.

In search of possible theoretical explanations for existence of EKC a rich and diverse body of literature has emerged. One of the main argument put forward is that the relationship signifies the transition of economic progress wherein the dominance of agriculture sector is replaced by industry and later by services sector (Arrow et al., 1995). While this argument per se is very powerful, it could not address the fundamental policy question underlying the EKC debate – namely, does regulation have any role to play? Other explanations put forward on the other hand have

[1] See Panayotou (2003) and Stern (2001) for recent review of literature on EKC.

resulted in providing opposing normative implications. For instance, Jones and Manuelli (2000) argue that poor countries may not have institutions that would enable them to internalize the externalities. This explanation has positive normative implication as it indicates that global community could have a role to play in helping the poor countries to self regulate. However opposite normative implications are also considered feasible because for low-income countries degradation of their local environment could be efficient as observed by Levinson (2000) while reviewing the studies by John and Pecchenino (1994) and Stokey (1998).

As an alternative to these explanations based on dynamic representative agent framework, recent studies by Andreoni and Levinson (2001) and Pfaff et al. (2002a, b) put forward micro level explanations. These studies argue that micro framework would be appropriate as the household models operate within a setting of internalization[2, 3]. Considering a household's choice of services (say, cooking requirements) and the share of 'clean'[4] fuel in the total fuel consumption required for providing the services, Pfaff et al. (2002a; 2002b) observe that given the household's ability to substitute between marketed goods, decision on *how much* services to consume could be separated from *how to* produce those

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[2] Chimeli and Braden (2002) note that such static models tend to simplify the analysis and may lead to policy recommendations that are not effective in a dynamic setup.

[3] It must be kept in mind that in case of outdoor pollution it is not feasible to establish relationship between income and pollution using household level data, as because of its insignificant impact on overall provision of good, the individual's marginal valuation of good is not affected by her income. However, in the case of indoor pollution since individuals value health and other benefits derived through decrease in pollution it is possible to observe the effect of individual's income on its marginal valuation of environment.

[4] 'Clean' fuels are those that emit relatively less local pollution. Examples of 'clean' and 'dirty' fuels in the context of cooking include liquefied petroleum gas and firewood, respectively.

services. The combined effect of these two decisions is what determines the indoor pollution and since each of these decisions is influenced by income the overall relationship between pollution and income could be non-monotonic. For instance, if 'dirty' inputs are inferior and 'clean' inputs are normal after a certain threshold income, then pollution-income relationship could be inverted U-shaped.

The empirical literature that was sparked off by the original studies has focused on two aspects – to check the robustness of the original findings and to extend the analysis to cover other pollutants and other datasets. In the second branch of studies, by and large empirical evidence shows existence of EKC for several pollutants with exceptions for pollutants like carbon dioxide, which perhaps could be due to strong dependence of economic activities on fossil fuel usage and lack of incentive for any one country to regulate emissions for such global pollutant with cross-boundary externalities. One of the recent entrants into this branch of studies is indoor air pollution. Chaudhuri and Pfaff (2002) studying emissions from cooking fuels used by the households in Pakistan found evidence for existence of EKC. Through its focus on indoor air pollution generated through cooking fuel usage in a large country like India the present study attempts to throw further light on empirical evidence for EKC.

Indoor air pollution is caused mainly through combustion of various solid fuels used for cooking and lighting purposes by the households. A large proportion of rural households depend on these bio fuels in India and a number of studies have highlighted, besides other things, the health risks associated with these fuels. Smith (1998) showed that about 5,00,000 premature deaths annually in children under five and women in India could be attributed to the indoor pollution caused due to bio fuel usage. Parikh et al. (2001; 2003) have also studied the health implications of bio fuel usage among rural households and highlight the importance of focusing on disease burden caused by indoor air pollution in the policy context.

A wide range of factors including affordability and awareness of the household, and availability of a particular fuel influence the household's choice of fuel. Viswanathan and Kumar (2003) while analyzing the trends in cooking fuel consumption have identified significant spatial and rural-urban differences and showed income as one of the main determinant of bio fuel consumption. Supply constraints of 'clean' fuels, especially kerosene and LPG, also limit the consumption of such fuels by the rural households.

Monotonic or non-monotonic pollution-income relationship has important policy implications. If the said relationship is non-monotonic – namely, pollution initially increasing and then declining with income, then from policy perspective it might be useful to identify various strategies that could help in reduce pollution emitted by the low-income households. By analyzing the relationship between income and indoor air pollution with focus on household level data on cooking fuel consumption in India, the present study aims to provide such policy inputs. The paper is structured as follows: the next section describes the dataset used along with the limitation inherent in the dataset, and provides a brief discussion on patterns of cooking fuel consumption revealed by the dataset. The third section outlines the model used to estimate the Engle curves and the pollution-income relationship. The fourth section presents the regression results and also the simulated income pollution relationship. Finally the last section discusses policy issues and concludes the paper.

2.0 Data

2.1 Source, Definitions and Limitations of Data

The study uses household level data collected through primary survey by the National Sample Survey Organization (NSSO) of India. The dataset provides information on household consumption expenditure of the fuels used for cooking and lighting. The NSSO collects this information during its quinquennial rounds (i.e., rounds conducted once in every five years) on a large sample of households in both rural and urban areas across all states of India. The present study uses data from three such rounds representing the past two decades. The specific years to which the data corresponds are: 1983 (38^{th} round), 1993-94 (50^{th} round), and 1999-2000 (55^{th} round). For estimation purpose the data corresponding to seventeen major states of India is used and for the study period these states represent about 90% of the total population of the country. The data set includes quantity and expenditure data for all major cooking fuels – firewood, dung, coke, coal, kerosene, gobar gas and liquefied petroleum gas (LPG)[5]. Besides information on cooking fuels, the dataset also provides data on monthly per capita expenditure (used as proxy for income in the study), and household characteristics such as its size and number of children. The fuel prices are not reported in the dataset, and hence the unit values obtained as ratio of expenditure to quantity are used as a proxy for fuel prices. Prices of proximate households are used as representative price for households with zero consumption.

[5] It may be noted that the NSS records information on use of fuel for cooking and lighting together. While for most fuels the primary use for cooking or lighting is distinct, fuels such as kerosene could be used for both. While kerosene is used mainly for cooking by the urban households, it is used primarily for lighting in rural households.

The cooking fuels listed above are categorized into two groups – ‘clean’ and ‘dirty’, based primarily on their local pollution potential. The study categorizes kerosene, gobar gas and LPG as ‘clean’ fuels, and firewood, dung, coke and coal as ‘dirty’ fuels. The cooking fuel expenditure is defined as the sum of expenditure on all fuels used for cooking, and the expenditure share of ‘clean’ (‘dirty’) fuels is the ratio of expenditure on ‘clean’ (‘dirty’) fuels to total cooking fuel expenditure.

The dataset used has following limitations:

- As mentioned above kerosene is used for both cooking and lighting purposes, particularly in rural areas. Following the procedure adopted in ESMAP (2003) the qualitative information on primary source of fuel for lighting and cooking provided in the dataset is used to allocate kerosene between cooking and lighting. However, in contrast to ESMAP (2003), the present study uses state level average consumption of kerosene across different categories of households while allocating it for cooking and lighting.
- Information on other dirty fuels like crop residue is not reported in the dataset[6]. Some studies (ESMAP, 2002) based on primary surveys report that rural households in states such as Punjab and Haryana, where crop residue supplies are abundant, use such fuels irrespective of income level. This movement down the energy ladder could be attributed to the scarcity of firewood and non-availability of fuels such as kerosene in rural areas. The lack of information on such fuels would under estimate ‘dirty’ fuel consumption in this study.
- Quantity data on certain fuels like dung are not available for all the three time periods and similarly for LPG in 1983. The

[6] A number of fuels are clubbed under ‘others’ category.

pollution estimates that use quantity data are affected by this data constraint and result in lower estimates of pollution from this study.

2.2 Pattern of Cooking Fuel Consumption in India

For the period of analysis the data shows wide variation in quantity and quality of cooking fuel consumed across three dimensions: (a) rural-urban, (b) rich-poor, and (c) across geographic regions. This section briefly discusses these patterns, whereas more detailed discussion including state level analysis of 'clean' fuel penetration and the factors influencing the 'clean' fuel penetration is presented in a related study by the authors (Viswanathan and Kumar, 2003).

Table 1 shows the average expenditure share of 'clean' fuels and also of different fuels for rural and urban households over the study period. For the rural households the 'clean' fuel expenditure share is far lesser than that observed among urban households, and its rate of penetration over time is also fairly slow. Between 1983 and 1999-2000 the 'clean' share in rural areas increased from 19.5% to 22.5% while in the urban areas it increased from 38.8% to 70.1%. The constituents of cooking fuels among rural households are mainly firewood and dung accounting for about 80% of the total cooking fuel expenditure. Even in 1999-2000 'clean' fuels like LPG constitute a very small share of about 4%. Though the expenditure share of the other 'clean' fuel, kerosene is relatively more (about 18%), a significant portion of that fuel might be put to use for lighting needs in rural areas. On the other hand the urban households have shown rapid shift away from 'dirty' fuels like firewood and dung whose expenditure shares declined from 50% in 1983 to about 26% in 1999-2000. Among the 'clean' fuels kerosene is more like a transition fuel whose share increased marginally between 1983 and 1993-94 to 32.2% and then decreased by

1999-2000 to 28.2%. The other 'clean' fuel LPG shows a significant jump from about 7% in 1983 to 29% in 1993-94 to about 42% in 1999-2000 making it the dominant cooking fuel.

Table 1 also shows the proportion of households consuming different fuels and the trends are similar to those observed with average expenditure shares. The rural-urban contrast is also stark with regard to the quantities of various fuels consumed. Table 2 shows the average monthly per capita consumption of firewood and kerosene (representing 'dirty' and 'clean' fuels, respectively) across rural and urban households over the study period. While the per capita consumption of firewood remained at a high level of about 19kg among rural households, its consumption reduced by almost half during the period 1983-2000 in the urban areas. Though kerosene consumption among rural households showed an increasing trend over the period it remained lower than that in urban households.

The cooking fuel consumption pattern is also significantly different across households with different economic status, with differential rates of penetration of 'clean' fuels. Figure 1 shows the 'clean' and 'dirty' fuel expenditure shares across expenditure deciles[7]. Though in the rural areas 'dirty' fuel dominates even for the richer households, 'clean' fuel is slowly making a dent by 1999-2000 among the top two-three expenditure deciles. The contrast between the richer and poorer expenditure deciles is more apparent in urban areas. The bottom 10% of the population increased their share of 'clean' fuel from about 20% to 30% between 1983 and 1999-2000 whereas the top 10% increased their share from about 65% to nearly 100% during the same period.

Finally, the data shows large regional differences with a few states having significant 'clean' fuel penetration over the study period both in rural and urban areas, a few other states largely dependent on 'dirty' fuels even in 1999-2000, and the remaining states that lie between the two. In rural areas though all the states had near similar expenditure shares for 'clean' fuels in 1983, by 1999-2000 the states like Gujarat, Himachel Pradesh and Maharashtra have increased their 'clean' fuel expenditure shares. In contrast states like Bihar, Madhya Pradesh and Orissa show a marginal decline in 'clean' fuel expenditure share. In urban areas states like Gujarat, Himachel Pradesh, Maharashtra and Punjab show higher 'clean' fuel expenditure share in 1983 itself and increase further over the study period. A large number of states (including Andhra Pradesh, Haryana, Karnataka and Tamil Nadu) show domination of 'clean' fuel expenditure by 1993-94, whereas a few states (Bihar and Orissa) show a much slower penetration of 'clean' fuels (see, Viswanathan and Kumar, 2003 for further details).

3.0 Model Specification

The study estimates Engel curves for the aggregate fuels – 'dirty' and 'clean', and pollution-income relationship for each time period and for rural and urban households separately. Model specification and econometric issues are discussed in this section.

3.1 Aggregate Fuel Engel Curve

The Engel curve for aggregate 'clean' and 'dirty' fuels is estimated using the following equation:

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[7] Deciles are formed by ranking the entire population according to monthly per capita expenditure and then dividing population into ten equal groups with each group containing 10 per cent of the total population.

$$q_h = \alpha_1 + \alpha_2 y_h + \alpha_3 y_h^2 + \alpha_4 y_h^3 + \alpha_5 y_h^4 + \alpha_6 n_h + \alpha_7 c_h + \sum_j \beta_j Z_h^j + u_h \qquad (1)$$

q_h – per capita quantity consumed per month of aggregate fuels

y_h – per capita monthly total expenditure

n_h – household size

c_h – proportion of children below 15 years age

Zh^j – control variables including fuel prices, dummies for sub-rounds and states

u_h – residual term

The regression model is a fourth order polynomial in per capita monthly total expenditure and includes other control variables. The dependent variable is per capita quantity of 'clean' and 'dirty' fuels consumed by the household. The fuels are aggregated into 'clean' and 'dirty' categories to allow for fuel substitutability within the categories. The aggregate fuel quantities are estimated using fuel specific heating values. Thus the dependent variable is expressed in energy unit megajoules.

The effect of explanatory variables, especially income, could be different on two related but separate aspects of fuel consumption – namely, probability of use and quantity consumed conditional on use. Hence the estimation procedure should address these two aspects and following Greene (2003) the study uses modification of the Tobit model suggested by Fin and Schmidt (1984). Thus, the estimation procedure includes a Probit model to assess the impact of income on probability of using either 'dirty' or 'clean' fuels, and then a truncated regression model to assess effect of income on quantity of chosen aggregate fuel. As observed in related studies (Chaudhuri and Pfaff, 2002) these generalized Tobit estimates are superior to simple Tobit estimates.

The model includes representative prices of 'dirty' and 'clean' fuels (firewood and kerosene, respectively) to control for prices[8]. Other control variables include, household size (n_h) to account for the economies of scale in household consumption, and the proportion of children (c_h) to control for the household composition effect. One expects that as the household size increases the amount of fuel consumed does not rise by the same proportion but a little lesser due to the scale effect and a household with larger proportion of younger children would have lesser cooking requirement. Apart from these some qualitative variables are also used: sub-rounds are included to account for seasonal variation in certain fuels mainly those constituting 'dirty' fuels; and fixed effects for the regions classified on the basis of states.

3.2 Pollution-Income Relationship

To analyze the EKC hypothesis the study estimates pollution-income relationship. Moving from fuel consumption to pollution involves a range of intermediate steps wherein information on quality of fuel, stove efficiency, and kitchen dimensions would be required. For want of information on all these variables, pollution generated at the household level through cooking fuel consumption is assessed in this study following a simple specification proposed by Chaudhuri and Pfaff (2002).

$$Pollution = (\rho q_d)^{\theta} + (q_c)^{\theta} \tag{2}$$

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[8] For the households with zero consumption of either firewood or kerosene, the prices of proximate households with positive consumption are used.

where, q_d and q_c are aggregate 'dirty' and 'clean' fuel consumptions in megajoules

ρ is the ratio of emissions from 'dirty' to 'clean' fuels, and

θ represents degree and direction of non-linearity of emission accumulation and translation to pollution.

A higher (lower) value of ρ indicates larger (smaller) difference in pollution generated by the 'dirty' and 'clean' fuels. Similarly, $\theta > 1$ (< 1) indicates that marginal increase in pollution with an additional unit of fuel rises (falls). While a range of values could be used for ρ and θ, the study assumes these values to be 100 and 0.5, respectively. The pollution variable as calculated in equation (2) above is used to estimate the regression model as in equation (1) using OLS with the explanatory variables (with the exception of price variables) remaining the same.

Finally, to simulate EKC the predicted values of pollution from the pollution-income regression are plotted against monthly per capita expenditure of the households. For comparability the predicted pollution is normalized with the pollution corresponding to the minimum expenditure household to generate indoor air pollution index and the same is plotted against household per capita expenditure.

4.0 Results

4.1 Aggregate Fuel Engel Curve

Tables 3 and 4 show the aggregate fuel Engel curves estimated for rural and urban households. Each table shows the Engel curves estimated for 'dirty' and 'clean' fuels for the years 1983, 1993-94 and 1999-2000. At the outset it must be mentioned that the adjusted R^2 values are low possibly because of following reasons: (a) the estimates are based on cross-sectional data for which the adjusted R^2 values are typically low; (b) the estimates are based on large sample data collected through primary survey, which could result in significant variation across sample in both dependent and independent variables. The goodness of fit of the specified functional form is highlighted by the fact that majority of the coefficients including income and its higher order terms are significant, as does the test statistics from F-test for overall significance of the models.

The price variables are not reported in the tables but in all the regressions the estimated coefficients are significant and have expected sign. That is, price of firewood has negative sign for 'dirty' fuels and positive sign for 'clean' fuels, and price of kerosene has positive sign for 'dirty' fuels and negative sign for 'clean' fuels.

The hypothesis is that for 'dirty' fuels the probability of use would decrease with income and the reverse would hold good for 'clean' fuels. Further, conditional on use the quantity consumed for both types of fuels would increase with income. The evidence from rural India however shows that for 'dirty' fuels the probability of use increases with income, probably due to easier access to such fuels in rural India. Results from the truncated regression model[9] show that quantity of 'dirty' fuels used, conditional on use, increases as expected with income at decreasing rate[10]. The estimates for urban households clearly show that probability of use of 'dirty' fuels

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[9] In some instances the truncated regression model did not converge due to few truncated observations. Hence, in such cases the study estimated OLS excluding the zero consumption observations.

[10] It may be noted that in Engle curve and pollution-income estimations, even though all the four income coefficients are significant the discussion is limited to income and income square coefficients as the signs for the other two coefficients follow similar pattern.

decreases with income, whereas conditional on use the 'dirty' fuel consumption increases with income.

For 'clean' fuels, barring a few exceptions in 1983 in rural India, the estimated coefficients have expected sign and significance. That is, probability of use of 'clean' fuels and quantity-consumed conditional on use, both increase with income. The coefficients for 1983 in rural India are not significant (though of expected sign) possibly due to very low consumption levels of 'clean' fuels and associated supply constraints.

Over time the magnitude of income coefficients in the truncated regression models decrease in both rural and urban India for 'dirty' as well as 'clean' fuels, perhaps indicating declining income elasticity of cooking fuel consumption.

The overall effect of household size on aggregate fuel consumption as argued by Chaudhuri and Pfaff (2002) can be interpreted through combination of three effects: (a) economies of scale in cooking services – that is, doubling the household size need not imply doubling of cooking fuel requirements; (b) scale economies in other consumption activities with positive income and negative substitution effects; (c) intra-household public good nature of indoor air quality – that is, larger households would benefit more from improvement in indoor air quality. The results show this combined effect of household size is negative for 'dirty' and 'clean' fuel consumption in rural as well as urban households. The negative effect of household size is stronger for 'dirty' fuels compared to 'clean' fuels in rural as well as urban areas. This could be because consumption of 'dirty' fuels contributes more towards deterioration of indoor air quality compared to 'clean' fuels, hence a unit increase in household size leads to larger decline in 'dirty' fuel consumption substantiating the public good hypothesis mentioned above.

With development due to increasing awareness about ill effects of 'dirty' fuel usage, one would expect the household size coefficient to become more negative for the 'dirty' fuels and less negative for the 'clean' fuels over time. The evidence from this study does support this, with the exception of 'dirty' fuel consumption among the urban households between 1993-94 and 1999-2000 where the household size coefficient increases marginally from –16.2 to –15.5.

Finally, barring a couple of exceptions, the households with larger number of children consume less 'dirty' as well as 'clean' fuels due to lower demand for cooking services. More importantly, negative effect is more pronounced in the case of 'dirty' fuels compared to the 'clean' fuels for reasons similar to those outlined for household size.

4.2 Pollution-Income Relationship

From the previous section it can be inferred that the relationship between aggregate fuel consumption and income is non-monotonic. The aggregate fuel consumption is translated into associated indoor air pollution using equation (2) and this section extends the discussion to address EKC hypothesis.

Table 5 reports the estimates of pollution-income relationship for rural and urban India over the study period. The coefficients of income and its square terms are positive and negative, respectively at all the three time points for rural India validating EKC hypothesis. On the other hand, in urban India evidence for EKC hypothesis is found only in 1983, with the other two years showing negative and positive coefficients for income and its square terms, respectively. As for the shape of EKC, since cubic and fourth order income coefficients are also significant the pollution-income relationship could be more like 'sideways-mirrored-S' than 'inverted-U'. Further, the results presented in Table 5 show the declining magnitude of income coefficient in both rural and urban India indicating that income had declining influence on pollution over time.

As expected, household size has positive effect on pollution because larger households need more cooking services. However the impact of household size on pollution is smaller in urban areas compared to rural areas due to greater dependence of the former on 'clean' fuels. Similarly, larger proportion of children in the household leads to lower pollution due to lower requirement for cooking services.

4.3 Simulated EKC

Figures 2 and 3 show the simulated EKC for rural and urban India, respectively[11]. Each figure shows the simulated curves at each of the three years of the analysis – i.e., 1983, 1993-94 and 1999-2000. The y-axis for each curve represents indoor air pollution index, which is the ratio of predicted pollution to the pollution corresponding to the household with lowest income, and the x-axis represents the monthly per capita total expenditure.

The simulated curves for rural India over the entire study period and for urban India in 1983 indicate that the pollution-income relationship follow 'sideways-mirrored-S' shape[12]. In urban India during 1990s

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[11] All the simulations reported are with the assumption that parameters ρ and θ take values 100 and 0.5, respectively. As expected higher value of ρ resulted in the turning point to take place at lower income level.

[12] It may be noted that accounting for other 'dirty' fuels like dung and crop residue would further delay the turning point along with steeper slope at lower income levels.

pollution declined at an increasing rate due to greater penetration of ‘clean’ fuels. The simulated curves for all India are similar in shape to those observed for rural India, reflecting the fact that significantly large population lives in rural areas in India.

While EKC hypothesis can explain first increasing and then declining shape of the pollution-income relationship, the second peak observed in the simulated curves needs further explanation. In order to gain insight about the possible reason for this feature per capita quantity of ‘dirty’ and ‘clean’ fuels (in megajoules) are plotted against monthly per capita expenditure and figure 4 shows the same for rural India in 1993-94. The second peak appears to be mainly due to corresponding peak observed in ‘dirty’ fuel consumption. As income increases service needs would be more and since ‘clean’ fuel supply has been limited in India – a feature of Indian cooking fuel supply that has been highlighted by many studies including a related study by the authors (Viswanathan and Kumar, 2003) – there is tendency to shift again towards ‘dirty’ fuels.

5.0 Conclusions and Policy Implications

Continuing dependence on bio fuels for cooking in India, especially among rural households, and the related health impacts caused by indoor air pollution have been causes of great concern. Even though the indoor air quality is primarily determined through household’s income and preferences (for different fuels), from policy perspective a pertinent issue to analyze would be the role of policies in enabling transition of the households towards use of ‘cleaner’ fuels. In this context existence of Environmental Kuznets Curve (EKC) for indoor air quality – that is, non-monotonic relationship between indoor air quality and household income – is a policy relevant empirical issue that deserves attention.

Using micro level data on household's preference for different cooking fuels this study estimated aggregate ('dirty' and 'clean') fuel Engle curves and pollution-income relationship for rural and urban India at three different time points of last two decades – i.e., 1983, 1993-94, and 1999-2000. The methodology adopted provided scope for analyzing the effect of income on two aspects of fuel consumption separately – namely, probability of use and quantity consumed conditional on use. With economic growth the probability of use of 'dirty' ('clean') fuel should decline (increase) with income as is observed for urban households during the entire study period. On contrary the results for rural households indicate increasing probability of use of 'dirty' fuels with income, perhaps due to easier access to such fuels. As expected the quantity consumed, conditional on use, increased with income in both rural and urban areas irrespective of fuel category.

The results of this study provide empirical support for EKC, especially among rural households for the entire study period and among urban households in 1980s. The pollution-income relationship becomes monotonic once the 'clean' fuel penetration improves as observed among urban households during 1990s. Validation of EKC hypothesis in the context of indoor air pollution is significant in itself as the households presumably internalize the adverse health impacts caused by such pollution while making their fuel choices. Even though the indoor air quality is primarily determined through household's income and preferences (for different fuels), from policy perspective a pertinent issue to analyze would be the role of policies in enabling transition of the households towards use of 'cleaner' fuels. The spatial and temporal analysis of pollution-income relationship presented in this study provides insights for such enabling policies.

- While the urban households showed rapid transition towards higher indoor air quality in the past two decades, the rural households suffer significantly from indoor pollution even in 1999-2000. The rapid transition towards ‘clean’ fuels in urban India is made possible mainly due to relaxation of supply constraints of those fuels. Important ‘clean’ fuels like kerosene and LPG are supplied to the urban households through well-organized networks (public distribution system and free market in case of kerosene, and free market in case of LPG) along with significant subsidies. The rural areas on the other hand do not benefit from such facilities. While it is well known that establishing distribution networks is far more difficult in rural areas compared to urban areas, the urban bias in supply policies – particularly of kerosene supplied through fair price shops – should be addressed on priority basis. Since the health impacts caused by indoor air pollution on the large rural population are relevant end points from policy perspective, existing policies that address emission reductions through, say improved cook stoves, should also be given further emphasis. Rural electrification on priority basis is also a relevant policy in this context as access to electricity for the rural households would enable them to use kerosene mainly for cooking (similar to what the urban households do).
- An interesting pattern observed in this study is the existence of a second peak in the pollution-income relationship and its transition over time in both rural and urban areas. As explained, this ‘sideways-mirrored-S’ shape of EKC could have been mainly due to limited supply of ‘clean’ fuels like kerosene and LPG in India. Over time these supply constraints have eased out and the study results document the manifestation of this through vanishing second peak in urban areas and reduced peakedness in rural areas. Again, to enable faster transition in rural areas in this regard, similar policies outlined above should be put in place.

Table 1

Average Expenditure Shares and Proportion of Households Consuming Different Fuels (in %)

	Rural			Urban		
	1983	**1993-94**	**1999-2000**	**1983**	**1993-94**	**1999-2000**
'Clean' Fuels	19.5	19.9	22.5	38.8	60.9	70.1
Firewood	59.0	59.7	58.5	42.1	28.7	22.5
	(85.6)	(86.4)	(87.3)	(61.1)	(41.2)	(32.0)
Dung	19.6	19.3	18.0	6.7	5.6	4.0
	(49.4)	(49.2)	(48.1)	(29.1)	(18.7)	(10.7)
Kerosene	19.3	18.3	18.2	31.7	32.2	28.2
	(94.8)	(94.9)	(95.5)	(92.6)	(82.4)	(74.3)
LPG	0.1	1.4	4.1	6.9	28.7	41.9
	(0.1)	(1.9)	(5.8)	(12.4)	(31.4)	(44.2)

Note: Figures in parentheses are proportion of households consuming different fuels.

Table 2

Average Monthly Per Capita Consumption of Firewood and Kerosene

	Rural			Urban		
	1983	**1993-94**	**1999-2000**	**1983**	**1993-94**	**1999-2000**
Firewood (kgs.)	18.5	19.3	19.3	11.2	7.3	6.5
Kerosene (lts.)	0.5	0.7	0.9	1.2	1.3	1.3

Table 3a

Aggregate 'Dirty' Fuel Engle Curve Estimates for Rural India: 1983-2000

	1983		1993-94		1999-2000	
	Probit	**Trunc#**	**Probit**	**Trunc#**	**Probit**	**Trunc#**
Inc	0.004	1.37	0.004	0.83	0.001	0.41
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
$(Inc)^2$	-1.74	-232.4	-1.08	-114.7	-0.4	-26.1
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.003)
$(Inc)^3$	2.33	265.2	0.81	68.0	0.24	6.9
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.23)
$(Inc)^4$	-0.92	-104.0	-0.18	-13.6	-0.04	-0.56
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.64)
HhSz	0.02	-14.5	0.01	-17.8	0.02	-18.1
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Child	0.04	-97.3	-0.07	-86.7	-0.2	-88.1
	(0.31)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Adj R^2	0.15	0.25	0.21	0.23	0.24	0.20
N	71074	63148	61696	54265	63478	55980

Note: (1) Inc – Income; HhSz – Household Size; Child – Proportion of children

(2) The figures in parentheses show the *p* values.

#: As the truncated regression model did not converge due to fewer truncated observations, reported estimates correspond to OLS model excluding the zero consumption observations.

Table 3b

Aggregate 'Clean' Fuel Engle Curve Estimates for Rural India: 1983-2000

	1983		1993-94		1999-2000	
	Probit	**Trunc#**	**Probit**	**Trunc#**	**Probit**	**Trunc#**
Inc	0.01	0.47	0.01	0.26	0.008	0.12
	(0.00)	(0.16)	(0.00)	(0.00)	(0.00)	(0.10)
$(Inc)^2$	-2.1	-98.0	-1.02	-29.6	-0.5	-10.3
	(0.00)	(0.41)	(0.00)	(0.00)	(0.00)	(0.27)
$(Inc)^3$	1.6	121.2	0.44	16.3	0.13	6.4
	(0.11)	(0.44)	(0.00)	(0.00)	(0.004)	(0.19)
$(Inc)^4$	-0.44	-53.9	-0.07	-3.1	-0.01	-1.4
	(0.32)	(0.40)	(0.00)	(0.00)	(0.18)	(-1.58)
HhSz	-0.078	-13.7	-0.003	-10.3	0.05	-5.9
	(0.00)	(0.00)	(0.54)	(0.00)	(0.00)	(0.00)
Child	0.40	-24.7	0.36	-11.3	0.18	1.1
	(0.00)	(0.17)	(0.00)	(0.01)	(0.00)	(0.87)
Adj R^2	0.25	0.30	0.27	0.32	0.3	0.15
N	71033	463	61640	2822	63307	6780

Note: Same as in Table 3a.

Table 4a

Aggregate 'Dirty' Fuel Engle Curve Estimates for Urban India: 1983-2000

	1983		**1993-94**		**1999-2000**	
	Probit	**Trunc#**	**Probit**	**Trunc#**	**Probit**	**Trunc#**
Inc	-0.007	1.25	-0.009	0.55	-0.006	0.33
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
$(Inc)^2$	0.74	-242.3	0.82	-66.5	0.35	-23.3
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.02)
$(Inc)^3$	-0.13	267.2	-0.32	33.6	-0.09	6.9
	(0.67)	(0.002)	(0.00)	(0.00)	(0.00)	(0.16)
$(Inc)^4$	-0.07	-102.8	0.04	-5.6	0.008	-0.69
	(0.583)	(0.005)	(0.00)	(0.002)	(0.00)	(0.37)
HhSz	0.04	-13.3	-0.0004	-16.2	-0.008	-15.5
	(0.00)	(0.00)	(0.91)	(0.00)	(0.002)	(0.00)
Child	-0.02	-77.6	-0.07	-66.2	0.055	-51.0
	(0.64)	(0.00)	(0.03)	(0.00)	(0.17)	(0.00)
Adj R^2	0.20	0.20	0.20	0.21	0.3	0.20
N	34914	24874	37145	15775	41481	14552

Note: (1) Inc – Income; HhSz – Household Size; Child – Proportion of children

(2) The figures in parentheses show the *p* values.

#: As the truncated regression model did not converge due to fewer truncated observations, reported estimates correspond to OLS model excluding the zero consumption observations.

Table 4b

Aggregate 'Clean' Fuel Engle Curve Estimates for Urban India: 1983-2000

	1983		1993-94		1999-2000	
	Probit	**Trunc**#	*Probit*	**Trunc**#	*Probit*	**Trunc**#
Inc	0.02	3.0	0.01	0.88	0.01	0.24
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
$(Inc)^2$	-5.9	-800.8	-1.6	-95.1	-0.80	-11.3
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
$(Inc)^3$	6.1	-828.6	0.73	42.9	0.27	2.31
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.05)
$(Inc)^4$	-2.1	-284.7	-0.11	-6.7	-0.03	-0.14
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.38)
HhSz	0.1	-27.5	0.15	-7.7	0.11	-4.3
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Child	-0.08	-2.0	-0.09	-37.9	0.03	-25.8
	(0.03)	(0.80)	(0.03)	-0.88	(0.54)	(0.00)
Adj R^2	0.20	0.24	0.20	0.40	0.24	0.10
N	34369	20737	36667	29856	40315	35463

Note: Same as in Table 4a.

Table 5

Estimates of Pollution-Income Relationship for Rural and Urban India

	Pollution					
	Rural			*Urban*		
	1983	**1993-94**	**1999-2000**	**1983**	**1993-94**	**1999-2000**
Inc	1.02	0.72	0.44	0.35	-0.71	-0.66
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
$(Inc)^2$	-315.9	-143.3	-62.8	-246.4	58.0	39.8
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
$(Inc)^3$	374.9	96.1	29.3	348.9	-19.1	-10.2
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
$(Inc)^4$	-138.3	-20.4	-4.6	-139.5	2.2	0.94
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
HhSz	19.9	18.9	17.8	21.1	11.7	6.9
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Child	-1.66	-11.4	-12.2	-7.4	-27.9	-15.8
	(0.55)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Adj R^2	0.24	0.20	0.20	0.24	0.30	0.30
N	71033	61640	63307	34369	36667	40315

Note: (1) Inc – Income; HhSz – Household Size; Child – Proportion of children

(2) The figures in parentheses show the *p* values.

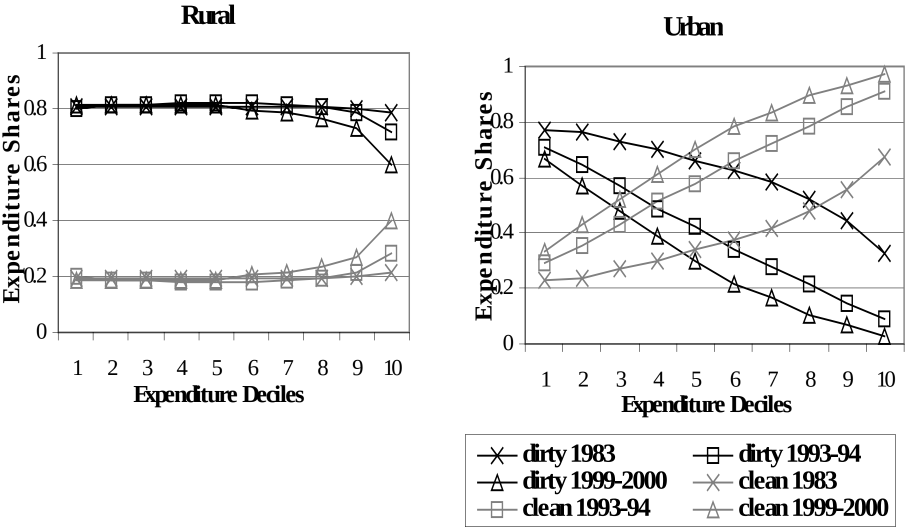

Figure 1
Expenditure Shares of ‘Clean’ and ‘Dirty’ Fuels Across Deciles

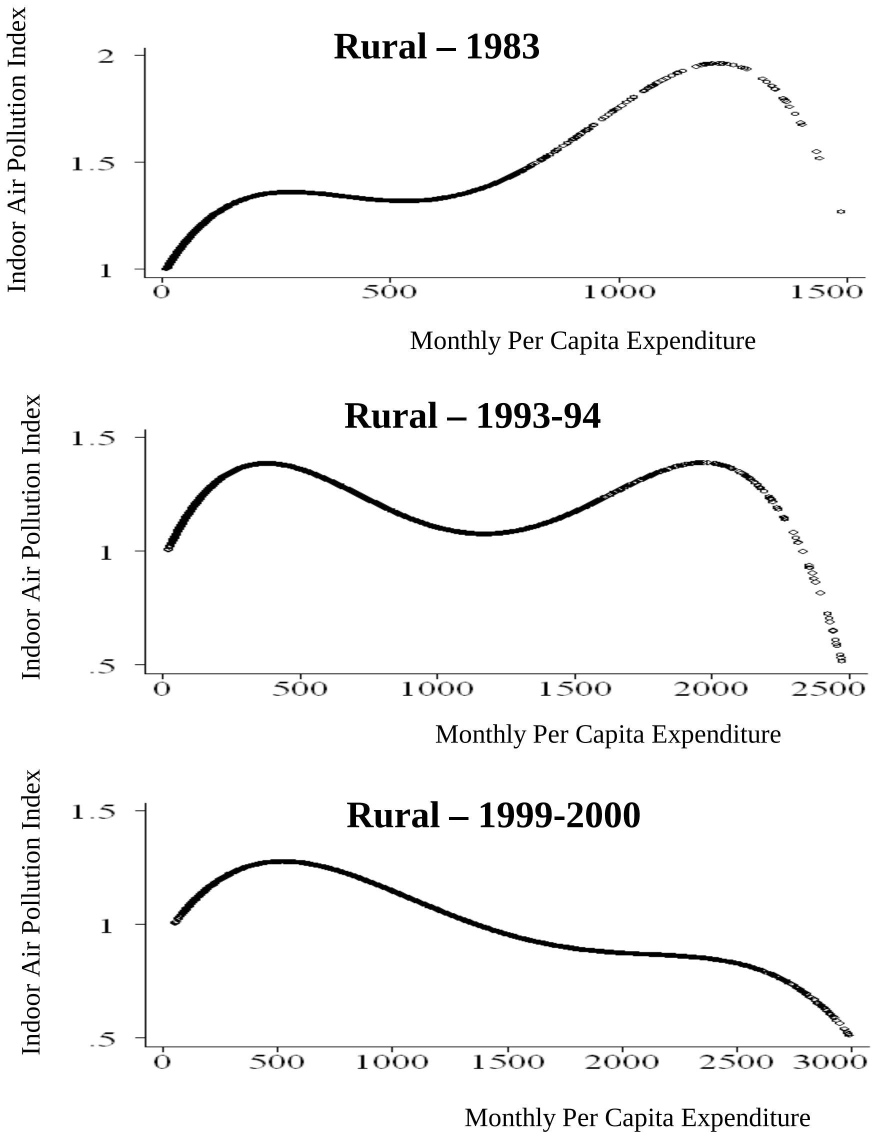

Figure 2
Pollution-Income Relationship: Rural India, 1983-2000

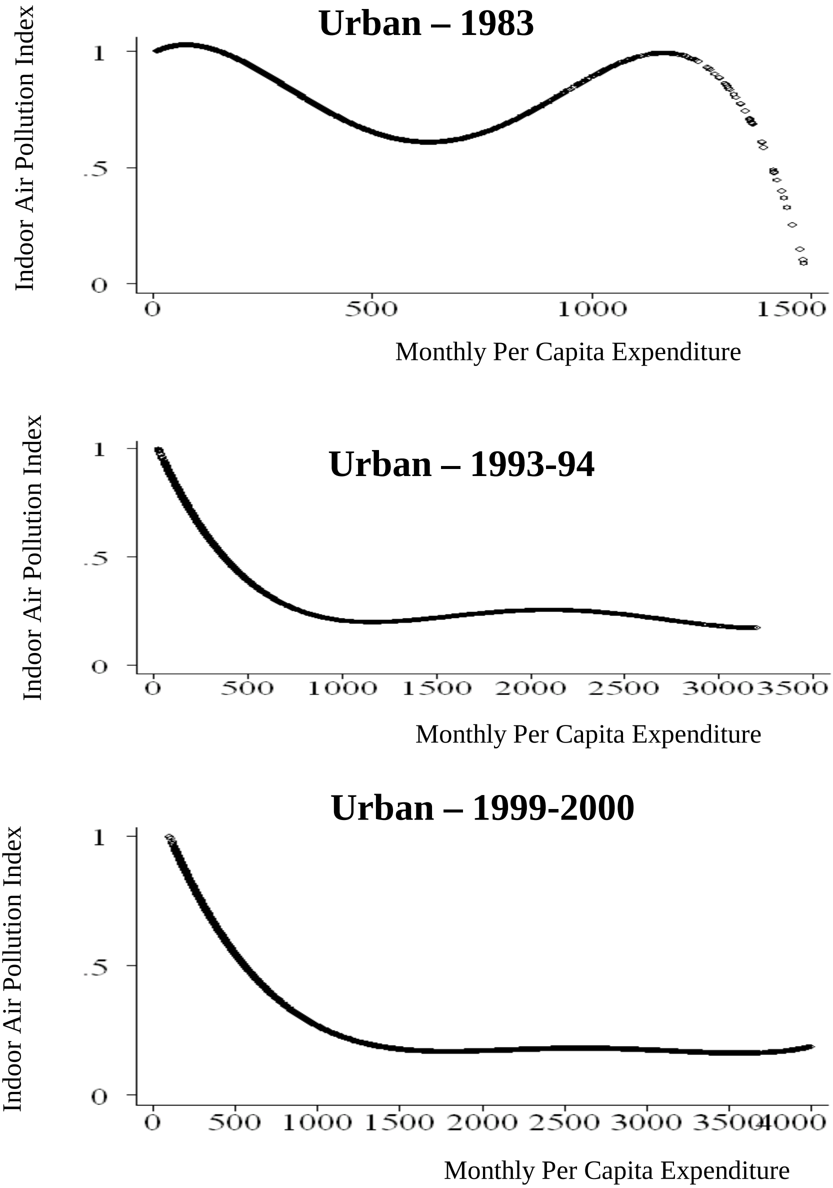

Figure 3
Pollution-Income Relationship: Urban India, 1983-2000

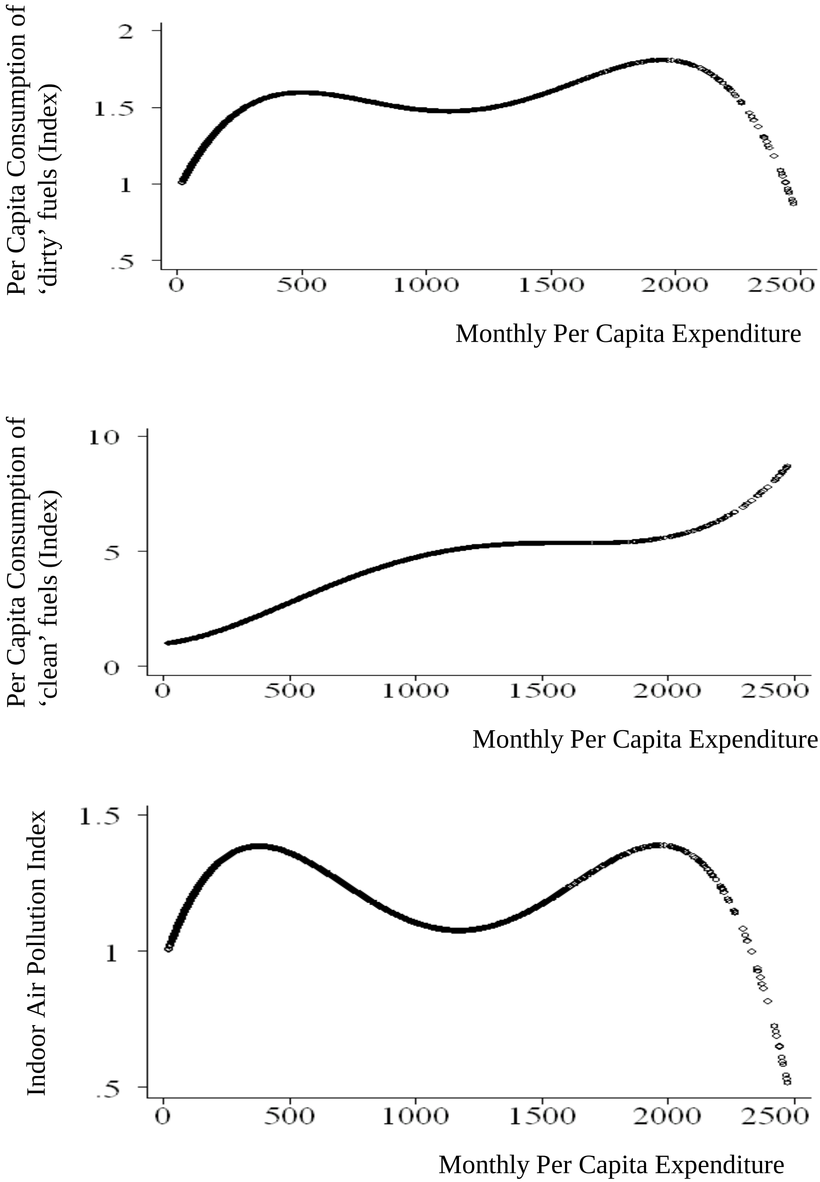

Figure 4
Decomposing Pollution-Income Relationship: Rural India, 1993-94

REFERENCES

Andreoni, J. and A. Levinson. (2001) 'Simple Analytics of Environmental Kuznets Curve', *Journal of Public Economics*, 80: 269-286.

Arrow, K., B. Bolin, R. Costanza, P. Dasgupta, C. Folke, C.S. Holling, B.O. Jansson, S. Levin, K.G. Mäler, C. Perings, and D. Pimental (1995) 'Economic Growth, Carrying Capacity and the Environment', *Science* **268**, 520-521.

Chaudhuri, S. and A.S.P. Pfaff (2002) 'Economic Growth and the Environment: What can we learn from household data?', Working Paper 0102-51, Economics Department, Columbia University.

Chimeli, A.B. and J. Braden. (2002) 'Economic Growth and Dynamics of Environmental Quality', European Association of Environmental and Resource Economists: Programme and Abstract Book. Southampton, England, p. 61.

ESMAP (2002) *Energy Strategies for Rural India: Evidence from Six States*, Joint UNDP/World Bank Energy Sector Management Assistance Program Report, Washington, D.C.

ESMAP (2003) *Access of the Poor to Clean Household Fuels in India*, Joint UNDP/World Bank Energy Sector Management Assistance Program Report, Washington, D.C.

Grossman, G. and A. Kreuger (1995) 'Economic Growth and the Environment', *Quarterly Journal of Economics*, 110 (2), 353-377.

John, A. and R. Pecchenino (1994) 'An Overlapping Generations Model of Growth and the Environment', *The Economic Journal*, 104 1393-1410.

Jones, L.E. and R.E. Manuelli (2000) 'Endogenous Policy Choice: The Case of Pollution and Growth', *Review of Economic Dynamics*.

Lenvison, A. (2000) 'The Ups and Downs of the Environmental Kuznets Curve', paper prepared for UCF/Center Conference on Environment, November 20-December 2, Orlando.

Panayotou, T. (1993) 'Empirical Tests and Policy Analysis of Environmental Degradation at Different Stages of Economic Development', Working Paper WP238, Technology and Employment Programme, International Labor Office, Geneva.

Panayotou, T. (2003) 'Economic Growth and the Environment', paper prepared for and presented at the Spring Seminar of the United Nations Economic Commission for Europe, Geneva, March 3.

Parikh J, K Balakrishnan K, V. Laxmi, H. Biswas (2001) 'Exposure from Cooking with Bio-fuels: Pollution Monitoring and Analysis for Rural Tamil Nadu', *Energy-The International Journal*, 26(10): 949-62.

Parikh, J.K., H. Biswas, and S. Karmarkar (2003) 'Cooking with Bio-fuels: Risk Factors Affecting Health Impact on Rural Women', *Economic and Political Weekly*, June 28: 2681-2692.

Pfaff, A.S.P., S. Chaudhuri and H.L.M. Nye (2002a) "Household Production and Environmental Kuznets Curves? Examining the Desirability and Feasibility of Substitution", *Environmental and Resource Economics* (forthcoming).

Pfaff, A.S.P., S. Chaudhuri and H.L.M. Nye (2002b) "Endowments, Preferences, Technologies and Abatement: growth-environment microfoundations", mimeo, School of International and Public Affairs, Columbia University.

Shafik, N. and S. Bandyopadhyay (1992) 'Economic growth and environmental quality: Time series and cross-section evidence', World Bank Policy Research Working Paper # WPS904, The World Bank, Washington, D.C.

Smith, K.R. (1998) *Indoor Air Pollution in India: National Health Impacts and Cost Effectiveness of Intervention*, Report prepared for Capacity 21 Project of India, Indira Gandhi Institute of Development Research, Mumbai.

Stern, D.I. (2001) 'The environmental Kuznets Curve: A review', in C.J. Cleveland, D. I. Stern, and R. Costanza (ed.), *The Economics of Nature and the Nature of Economics*, Edward Elgar, pp. 193-217.

Stokey, N.L. (1998) 'Are there limits to Growth?', *International Economic Review* 39(1): 1-31.

Viswanathan, B. and K.S. Kavi Kumar (2003) 'Cooking Fuel Use Patterns in India: 1983 to 2000', *Energy Policy* (forthcoming).