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Indoor Air Pollution in India: Determinants and Policies to Transition to Clean Energy Use

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In addition, some results are also based on the India Health, Environment, and Economic Development survey 2004 (IHEED). 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 grant R21AG02402101 from the National Institute of Aging to the University of Maryland.

Data collection was completed in November 2005 and the data are still being validated. These results are based on preliminary data and may change once final data are available.

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I INTRODUCTION

All over the developing world, women regularly cook meals over home-made traditional stoves or open fires. These stoves are fired with wood, branches, twigs or dung. When those are not available, women cook with agricultural residues or tree leaves. The smoke emitted from such stoves often blankets the entire room. In many homes, women cook in this haze with sleeping babies tied to their backs while the older siblings play nearby. This smoke is made up of fine suspended particulate matter that settles deep within their lungs when inhaled. With every meal cooked, day after day, they are exposed to a greater and greater degree of indoor air pollution. It is estimated that as much as 70 percent to 80 percent of households in countries like India, continue to use fuels like wood, dung and crop residues for cooking (IEA, 2002). The seemingly “free” availability of biomass fuels from nature makes them the primary fuel source for domestic purposes.

The problems related to the use of biomass as an energy source have been an issue of concern for well over three decades. The traditional stoves commonly used for burning biomass energy have long been found to be highly inefficient and emit copious amounts of smoke due to partial combustion of fuels (Ezzati and Kammen, 2001; Smith, 2000). This inefficiency in turn has had consequences on the environment, as intense collection of fuelwood has resulted in deforestation in highly populated areas (Ravindranath and Hall, 1995). In addition, the cost extolled in terms of human energy and time required to collect and process such fuel has serious implications for productivity and gender equity (World Bank, 2004; Sen, 2000).

Over the last decade sound epidemiological studies have provided mounting evidence of the damage caused to human health due to the pollutants released during combustion. Researchers have found a high incidence of acute respiratory infection (ARI), chronic obstructive pulmonary disease (COPD), chronic bronchitis and damage to the eyes among women in such households (Pokhrel et. al, 2005; World Bank, 2002; Smith, 1993). Furthermore, some studies indicate that there is a 50% greater chance of still-born births for women cooking on traditional stoves (Mishra et. al., 2005). By some recent estimates, 1.6 million infant deaths can be attributed to the use of solid fuels. Thus, the urgency to address this problem has never been greater.

Attempts to transition households from these fuels to modern fuels or from traditional stoves to efficient improved stoves through energy sector reform or indigenous innovative technology have been very effective in some countries, but quite dismal in India. In fact, India is now moving in the direction of abandoning Improved Chulha programs altogether despite sound evidence of it's effectiveness at reducing harmful emissions.

Our purpose in this paper is threefold. Using the recently collected India Human Development Survey- 2005 (IHDS), we first present the scope of the problem and examine the determinants of inter-fuel substitution for cooking. Second, using Health, Environment and Economic Development Survey-2005 (IHEED), we examine the degree of indoor air pollution and identify its major causes. Finally, we assess the policy implications in light of our findings and discuss some successful energy sector reforms in other countries that help to mitigate the problem.

OVERVIEW OF ENERGY USE

The adoption of modern energy sources in rural India has been slow. The use of traditional biomass fuels including firewood, wood chips, crop residue, and dung cakes for cooking and heating are still widespread in rural India. As shown in Table 1, 90% of rural households and 40% of urban households still rely on biomass as their primary cooking fuel. Half the rural households still use highly inefficient cooking fuels such as dung cake and crop residue.

To mitigate the negative effects of traditional biomass stoves, an attempt was made by various states to promote programs to install improved chulha with grates and chimneys. But this recent data shows that it is only used by 5% of rural households and 6% of urban households. Though it is the cleanest cooking fuel, LPG use is quite limited, especially in rural areas. Only 22% of rural households use LPG compared to 71% of urban households. However, it is encouraging to note that penetration of LPG in urban areas has gone up remarkably in the last decade. In terms of electrification, while 95% of urban households have electricity, only 69% of households in the rural area have access to electricity. Table 1 also shows that the energy use pattern in the smaller survey IHEED is generally comparable to IHDS[1].

Energy expenditures can be a big share of household expenditures. Table 2 shows the households' monthly expenditures by different fuels. When we look at buyers only, a clear pattern emerges, where rural households spend more on biomass fuels and less on clean modern fuels (kerosene, LPG, and electricity) than urban households.

DATA AND METHODS

In 2004 and 2005, the University of Maryland and the National Council of Applied Economic Research designed and fielded a multi-topic survey of over 40,000 Indian households. The India Human Development Survey, 2004-2005, was conducted throughout India in 35 states and Union Territories and included urban as well as rural areas. As part of the survey, respondents were asked about their fuel use, collection and consumption patterns for domestic use as well as various details about cooking, kitchen ventilation and the type of stove used. In addition, village level information on infrastructure was collected using a village survey

The Health, Environment and Economic Development Survey-2005 (IHEED) was conducted at about the same time but is based on a smaller purposive sample of 620 households in four states. The sampling was designed to capture the range of fuels used in India under different geographic and climate conditions. A multi-disciplinary collaboration between the University of Maryland, College Park, The Energy Research Institute (TERI), University of California, Berkeley and Sri Ramachandran Medical

[1] Because IHDS is nationally representative, we mainly use it to present the energy use and expenditure patterns in India. While IHEED has more detailed data on energy use and physical measures of IAP and other measures of health, we mainly use it for the IAP analysis, but also present the data to compare with IHDS whenever possible and use it to show the energy use patterns when IHDS does not have such data.

College, Chennai, the survey is unique in that detailed socio-economic information is combined with physical measures of indoor air pollution and health measures of household members have been collected. Together, the two surveys provide uniquely rich information on household energy use, environment, health, and development in India.

We use logistic regression on the IHDS data to analyze the determinants of fuel use. The dependent variable is a categorical variable which takes on the value of 1 if the household uses clean cooking fuels. For the second analysis on examining the determinants of indoor air pollution we use Ordinary Least Squares regression on the IHEED data. Because India has a very diverse socio-economic environment across states, we add state level control variables in the regression.

DETERMINANTS OF INTERFUEL SUBSTITUTION

Fuel use tends to vary with the socio-economic profile of households. In India, only 6% of rural households have completely switched to clean cooking fuels-charcoal, coal, kerosene, and LPG. By contrast, 65% of urban households have changed to clean cooking fuels. In terms of assets, it seems that the wealthier households are more likely to switch to clean cooking fuels because cooking fuels are more expensive. Since caste is an important stratifying principle in India, one must consider its impact when modeling fuel substitution. Table 3 presents the means for the IHDS data by these categories.

In addition to wealth, caste affiliation, and urbanization, past research has found some of the following parameters may also influence households' decisions on whether switching to clean cooking fuels-Access to electricity, Education, Land Ownership. In addition we include other hypothesis that our data allow us to test- Knowledge about the harmfulness of indoor air pollution; business ownership and household size.

(1) Access to electricity and pipe water. These two factors are included because the previous studies (Heltberg, 2004) have shown a strong linkage between these two factors and whether switching to clean cooking fuels.

(2) Education: Highest male's and female's education in the household. The rationale here is that households with higher education level have better understanding of benefits of switching to clean cooking fuels (Barnes et. al, 2005). In particular, higher education of the women in the household translates to higher opportunity costs of biomass fuel collection time, motivating fuel switching in order to save the time of these women.

(3) Land Ownership: If a household has a farm, they have easy access to free biomass such as crop residues, so we expect they are less likely to switch to clean cooking fuels.

(4) Business ownership: If a household has a non-farm business, they may have higher cost to use biomass fuels because more efforts are needed for collecting biomass fuels and the opportunity costs of biomass fuel collection time is also higher, thus we expect they are more likely to use clean cooking fuels.

(5) Household Size: We consider this factor because in a large household, cooking time is usually longer, so more fuels are needed. In addition, the opportunity cost of fuel collection time is relatively low because more laborers are available in a larger household. Thus, the cost of switching to cleaning cooking fuels will be high, so we expect they are less likely to use clean cooking fuels.

(6) Health beliefs that smoke from a wood/dung burning traditional chulha is harmful for health. We consider this factor because if households know that the smoke is harmful they should be more likely to switch to clean cooking fuels if they consider health impact in their decision making.

The regression results are presented in Table 4. All factors are statistically significant and in the direction we expected except for the health belief. We find that about 83% of households know that smoke from a wood/dung burning traditional chulha is harmful for health, but most of them continue to use it in their daily lives. This implies that purely educating people on the health impacts of biomass fuels would not be very effective to promote fuel switching. We find that Schedules Castes and Scheduled Tribes are more likely to stay with the biomass fuel and Brahmin and high caste are more likely to switch to the clean fuel. In terms of magnitude, assets level, urban location, and access to electricity are the leading contributors to fuel switching.

We next test whether the level of development of a village has an impact on fuel use. Because IHDS has data on development indicators at the village level, we are able to test this hypothesis. We construct three village level indices by aggregating the available development indicators:

(1) <u>Economic index</u> includes access to paved roads, electricity, land line phone, mobile phone service, bus service, a police station, a ration shop, a bazaar, a kirana store, a bank and a post office in the village.

(2) <u>Social infrastructure index</u> includes access to women's group, youth club, trade-unions, self-help group, caste association, religious association, NGO's, milk and agri. Coops, panchyat bhavan, pani panchayat, community center, community television set.

(3) <u>Public programs index</u> includes many kinds of employment work schemes, women's welfare, maternity, pension schemes, ration, safe drinking water, housing schemes, improved stoves, forestry, street and light program, child and infant care programs, and credit programs.

The regression results are presented in the second column in Table 4. We find that all the three indices are statistically significant in the direction we expected, lending support to our hypothesis that the level of development is a major factor determining rural households' fuel switching. Therefore, we can conclude that fuel switching on a large scale will not occur until rural areas have seen a substantial amount of development.

OVERVIEW OF IAP LEVELS

The World Health Organization estimates that exposure to indoor air pollution (IAP) causes about 500,000 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. In this section, we use the data from the IHEED survey which contains both socioeconomic and physical measures of indoor air pollution to analyze the levels and determinants of exposure to IAP in India.

Although there are hundreds of chemical species in biomass smoke, for most health outcomes of interest, concentration of small particles, less than 2.5 microns in size (PM 2.5) is used as the indicator of indoor air pollution. Although there is no safe level of particulate air pollution, the lower it is the better it is considered. For comparison, the US national ambient air quality standard for the annual mean PM 2.5 concentration is 0.05 mg/m^3 [2]. In the IHEED sample, a concentration of 0.35 mg/m^3 or greater is very common. Figure 1 presents the distribution of the 95^{th} percentile and mean PM 2.5 concentrations in kitchen and living area respectively and Table 5 shows the basic statistics of PM 2.5 concentrations. We can see that the average PM 2.5 concentrations in any measures have been far beyond the US national ambient air quality standard. In particular, we have some extremely high 95^{th} percentile PM 2.5 concentrations in kitchen.

In addition, we find that mean PM 2.5 concentrations in kitchen and living areas have a correlation of 0.27 as illustrated in Figure 2. Note that the PM 2.5 concentrations in living areas in our sample do not include households that have combined kitchen and living area. This indicates that air pollution from cooking diffuses into living spaces even if they are separate rooms. However, the concentration is much higher in the kitchen and thus the members who are affected more than others are often women and young children.

[2] Source: http://www.nrdc.org/air/pollution/bt/8780.asp

DETERMINANTS OF INDOOR AIR POLLUTION

In order to assess the factors that determine PM 2.5 concentrations, we use regression analysis to explore the relationships between the PM 2.5 concentrations in the kitchen and a set of variables that describe household cooking and ventilation practices, structure characteristics and building materials in addition to control variables on temperature and humidity. The regression model of the determinants of pollution in the kitchen is presented in Table 6. We use the 95^{th} percentile PM 2.5 concentrations for our dependent variable as it more closely approximates the actual pollution while cooking than the mean levels. To check if results are driven by some outliers, we also run a second regression using the sample excluding the extreme values greater than 20 mg/m^3. As shown in Table 6, the two regression results are very comparable.

We find that the primary stove using clean fuels significantly affects PM 2.5 concentrations in kitchen even after we control for only biomass cooking fuels, only clean cooking fuels, and mixed cooking fuels. The primary stove type stands out rather than the type of cooking fuels implying that partial fuel switching may not have a significant impact on the household IAP levels. Because if households use clean fuels only for making tea, but still use traditional biomass for cooking, the household IAP levels would not change much.

The location of the primary stove also shows a significant impact on PM2.5 concentrations. Compare to the stove in living room, stove in a separate kitchen with both inside and outside entrances has significantly less PM2.5 concentration.

Whether the wall is made from mud is also significantly positive in determining PM 2.5 concentration levels in the kitchen. This finding on the effect of mud walls is consistent with the study on Bangladesh (Dasgupta, S., et al, 2004a). The study finds that in most areas, the soil has low sand content and mud walls and floors are frequently re-coated with fresh mud to prevent cracking. This creates an effective seal that permits almost no ventilation in comparison with thatch and other building materials. If the cooking is inside the house, the sealing effect of mud walls increases the PM 2.5

concentrations. However, if the cooking is outside the house, mud walls in the living room have an insulating effect.

Number of people in the household also has significant positive correlation with PM2.5 concentrations even after controlling for cooking time. The reason may be that in addition to the prolonged cooking time, the cooking process is more intense if number of people in the household increase.

Furthermore, although improved chulha is not significant, it has the highest coefficient to reduce PM2.5 concentration. This indicates that when completely switching to clean fuels is hard, adopting improved chulha could be a cost-effective way to reduce IAP.

WHAT SHAPES THE ENERGY TRANSITION?

Given a choice, most households would rather use modern fuels for cooking. This is clear from the findings in the determinants of inter-fuel substitution where we find that households in urban areas are far more likely to make the transition to modern fuels. The widespread use of biomass fuels does not necessarily imply that it is the preferred fuel of choice. Given the option, many households have switched to commercial fuels or to the efficient use of biomass stoves.

There are several factors that seem to determine fuel choice, and they can be broadly classified into four inter-related categories (Barnes et al, 2005). The first is ***access*** to both modern fuels and to local biomass. The second involves ***affordability*** as determined by household income, as modern fuels must be purchased in the market. The third involves affordability as well, but relates to the ***government policies*** that have an impact on the price on commercial fuels. Finally, one option in the energy transition that is often ignored is the development and promotion of ***improved biomass*** stoves that are more energy efficient and vent smoke to outside of the house (Barnes et. al., 2005).

Access to Biomass and Modern Energy: The development of energy markets in developing countries is quite uneven. For modern fuels, the institutions serving both urban and rural markets can be quite diverse. In some countries government-run apparatus control the flow of kerosene and LPG; in others there is one dominant supplier that has a virtual monopoly; and finally in some others there is a significant degree of competition among a limited number of private companies. On the other hand, the supply of biomass generally is characterized by either own production or collection of the fuel, local sales, or a market chain that reaches out from urban to rural areas. There is growing evidence that if households have access to a variety of fuels, it results in greater acceptance of modern fuels in both urban (Barnes et al, 2005) and often in some rural areas.

Unfortunately, as wood becomes scarce due to deforestation, the use of agricultural residues as a source of energy use is on the rise. Not only are residues a very poor source of energy for cooking, it deprives farming soil of nutrients when it is not plowed back into the land.

Thus, energy access to both biomass and modern fuels is extremely important element of household fuel choice. However, as indicated there are other important factors as well. Probably the most important factor of all is household income. People with low income cannot afford either the stoves or the monthly cost of purchasing modern fuels for cooking.

Income and Affordability: Poverty is inextricably linked to biomass use. Modern fuels cost money. When households can afford to move up the energy ladder and access to modern fuels is not an issue, the transition is almost inevitable. The energy ladder ranges from dung and straw at the lowest rung to electricity at the highest rung. Most homes in the developed world use either electricity or natural gas for cooking. These sources are the most efficient and clean burning. Most homes in developing countries still use biomass energy, but there is a growing transition to modern fuels and a somewhat worrisome trend in the opposite direction as well. However, as indicated above, affordability is only an issue if there is adequate access to modern fuels and access is often dictated by whether a household lives in an urban or a rural areas.

Fuel Polices for Urban and Rural Markets: Governmental policy is another factor influencing the evolution of energy markets, and this is especially true for urban areas in developing countries. As indicated in a previous section, such policies are more relevant for urban areas than rural ones mainly because of the predominance of collected biomass energy in rural areas. However, a few recent studies (IHDS and Bangladesh, Peru) are beginning to find that increasing pressure on rural biomass energy means the commercial fuels are becoming viable even in some rural areas today. This is especially the case in Latin America where modern fuels are increasingly being used for cooking by people in rural areas.

The implementation of pricing policies, quantity rationing, or import controls can alter the pacing and expression of the urban energy transition. Kerosene subsidies can encourage more rapid fuel-switching from wood and/or induce consumers to continue kerosene consumption for an extended time period, while kerosene taxes can have the dichotomous effect of delaying the energy transition for low income consumers, but accelerating the switch time at which higher-income people choose LPG or electricity. Government policies also influence the market penetration of modern fuels in larger cities through access and/or quantity constraints.

For urban areas in developing countries, commercial energy prices such as kerosene or LPG often provide a cap for biomass prices. Generally biomass energy in the form of wood or charcoal is freely bought and sold in urban areas of the developing world. As a consequence, the price of wood and charcoal is set by market forces. However, there are policies to either tax or subsidize fuels in many countries. As a result, when the price of commercial fuels rises, they are followed by a similar rise in the prices of biomass energy once end use efficiency is taken into consideration.

Haiti is one of the few countries for which a time-series data on charcoal prices are available for a particular period. Forest cover in Haiti dramatically declined during the 1970s as a consequence of demand pressures associated with high population growth rates. By 1978 the total forest cover had shrunk to only 6.7 percent of land area (see Stevenson 1989; Lewis and Coffey 1985). During this period, the real price of charcoal in Port au Prince rose at an average annual compounded rate of just over 6 percent per year. In about 1988 the price of charcoal caught up with the backstop prices of LPG and kerosene. The prices of the three fuels were fairly competitive in the study period following (Figure 4). Although few poor people in Haiti use LPG or kerosene, mainly because of poor access to such fuels, the price of charcoal has risen along with other commercial fuels. This is both a consequence of the resource pressures noted, but also because taxes on kerosene and LPG have displaced some demand to charcoal (World Bank, 1991).

For a similar time period in the major city of Hyderabad in India, one can see that the price of useful energy for cooking is actually somewhat higher than the commercial alternatives. The reason for this may have been due to a system of rationing kerosene and a shortage of LPG in the marketplace. As a consequence, poor people in Hyderabad during this period were actually paying more per unit of energy for cooking than their richer counterparts who were able to use LPG or kerosene. This gives a view of the consequences of policies that limit the amount of modern fuels in the urban marketplace, as it is the poor biomass using households that get hurt.

Obviously higher prices in a region with significant biomass energy will delay the transition of people to modern fuels because they have biomass energy freely available to them. This will delay the transition to modern fuel for many people. Thus it is not recommended as is common in some African countries, to highly tax commercial fuels that can be used for cooking. In India the government provides both subsidies and rations fuels. This is also not recommended as it does nothing to rationalize fuel prices, and generally causes distortions in energy markets (Figure 6, see China and Indonesia). Providing subsidies and making available unlimited supplies of commercial fuels does have a positive impact on promoting inter-fuel substitution. However it also distorts the market for these fuels and they often are siphoned off to the transport sector. Thus, the pricing policies recommended to promote inter-fuel substitution are to have very light taxes on them and make the fuels available in both urban and rural areas in sufficient quantities to meet the demand of the populations that can afford them.

ENCOURAGEMENT OF EFFICIENT BIOMASS STOVES: A SOLUTION FOR THE POOR?

One overlooked program that can provide a bridge between biomass energy and the switch to commercial fuels is the improvement in the stoves that use biomass. This generally is less expensive for households dependent on biomass and such stoves are often designed with chimney to vent smoke out of the home. As our model on the determinants of pollution showed, biomass improved stoves reduce smoke in households that use them, but the reduction is not as significant as for a household that would switch completely to LPG. The problem is that the international effort to promote improved biomass stoves has a somewhat checkered history. In this section we will compare the international best practices to a program that has recently been cancelled in India due to problems in getting a high number of households to adopt and keep using them.

The international programs for improved stoves can provide some insights into both the successes and problems involving the promotion of efficient biomass stoves. Based on a recent review of stove programs in India and China (Barnes et al, 2005), there are some insights and recommendations that can be made concerning the promotion of improved stove programs around the world. In addition, there is recognition that energy efficiency and increasingly improved health can be important selling points for improved stoves.

The lessons of international programs are compared to a program in India that has recently been cancelled due to poor performance (Table 7). The most successful international programs target subsidies towards the commercialization of the stoves rather than providing the user with extensive subsides. The idea is to stimulate entrepreneurs to build the stoves and to create a real market for them. The role of subsidies in India's program is mixed. On the one hand, in the successful programs subsidies have encouraged possible stove owners to purchase them. However, once purchased, there are no follow-up subsidies for spare parts and maintenance. Subsidies can be used to support the development of the technical backup units, quality control facilities for testing stoves, monitoring surveys for discerning stove functionality and the opinions of users concerning the stoves, and training of education regarding subjects such as stove design, indoor air pollution, and energy efficiency. However, this should be done in a way that integrates the design, construction, and convenience of the stoves for users.

Further, the role of the government should be to support the process of commercialization. This can be done through the formulation of policies to provide incentives to private sector operators to produce, distribute and sell improved stoves. Government assistance can also take the form of providing technical standards, facilitation of the availability of raw materials, credit facilities for stove makers and promotional support.

The best international programs have developed stove programs in the regions with the greatest needs to conserve energy, such as regions that have significant biomass shortages and emerging markets in the sale of fuelwood. Therefore, it is recommended that the selection of villages for program participation be based on such factors as biomass shortage, concern for the health implication of traditional stoves, coordinated with campaigns to inform rural people about the health problems associated with indoor smoke, concern for clean kitchens by users, and a cooperative local government or administrative unit.

The availability of components and component parts appears to be a weakness in most of the programs. The producers and users complained about the availability and quality of the stove components. There needs to be greater coordination to make the development of quality, and if possible inexpensive, stove components a central part of the program. This requires a greater interaction between the technical backup units and the component makers.

Promoting Improved Stove programs successfully should be an essential interim strategy in areas where biomass is abundant and poor households cannot afford modern fuels. Not only is the combustion more efficient in such stoves, reducing to need to use copious amounts of biomass, but it also drastically reduces indoor-air pollution.

CONCLUSION

As research provides mounting evidence of the toll biomass use takes on the daily lives especially of women and children in the poorest parts of the developing world, this paper has shown that its persistent widespread use depends largely on the factors of access, affordability and pricing policies. Some of the lessons learned from best practices around the world are quite encouraging.

We find that 90% of rural households in India still rely on traditional biomass as the primary cooking fuels. Assets level, location, and access to electricity are identified as the leading contributors to fuel switching in addition to other factors such as female education and ownership of farmland. Health knowledge on the harmfulness of smoke from a wood/dung burning traditional chulha on the other hand, does not seem to have impact on fuel switching. In fact, more than 80% people have this health knowledge. Therefore, simply letting people know the health impact will not make a big difference on fuel switching. We find that in rural area, the level of development is a significant factor determining fuel switching. Therefore, fuel switching on a large scale will not occur until rural areas have seen a substantial amount of development.

In terms of determinants of IAP levels measured as PM 2.5 concentrations, we find that primary stove type, its location, mud wall, and the numbers of people in a household are significant factors that determine PM 2.5 concentration levels in the kitchen. In addition, improved chulha is potentially a leading factor that reduces maximum PM 2.5 concentrations because it has the highest coefficient. Therefore, adopting improved chulha is the most cost-effective interim strategy to reduce IAP if completely switching to clean fuels is not practical. Given the fact that only 5% Indian households are using improved chulha and large-scale fuel switching in rural areas may not be possible in the near future, promoting improved chulha seems to be the most effective policy.

Using the uniquely rich data from the two surveys, future research should continue to investigate the relationship between energy and development, such as to understand both conceptually and empirically how households make energy choices and to provide empirical evaluations of the impact of development.

Table 1 Overview of Energy Type by Urban and Rural in IHDS and IHEED

		IHDS		IHEED		
	Total	Rural	Urban	Total	Rural	Urban
Sample size (# of HH)	40731	64%	36%	622	66%	34%
Energy Use						
Firewood	71%	91%	36%	80%	88%	64%
Wood chips	N/A	N/A	N/A	18%	20%	14%
Crop Residue	14%	20%	2%	17%	23%	7%
Dung Cakes	37%	50%	13%	43%	49%	31%
Charcoal				1%	1%	2%
Coal	5%	3%	7%	8%	6%	14%
Kerosene	76%	87%	54%	78%	81%	73%
LPG	40%	22%	71%	35%	32%	41%
Electricity	78%	69%	95%	78%	75%	84%
Primary Stove						
Open fire	23%	28%	13%	20%	23%	15%
Chulha	45%	57%	21%	50%	56%	37%
Improved chulha	5%	5%	6%	1%	2%	0%
Gas/kerosene/elec	27%	10%	60%	29%	19%	48%

Table 2 Households Fuel Expenditures (Rupees/month) -Buyers Only

Type of Fuels	IHDS		IHEED	
	Rural	Urban	Rural	Urban
Firewood	177	153	143	160
Wood Chips	n.a.	n.a.	23	48
Dung Fuel	103	75	n.a.	n.a.
Crop Residue	92	48	n.a.	n.a.
Charcoal/Coal	140	132	93	235
Kerosene	44	72	52	93
LPG	226	277	399	613
Electricity	137	262	181	221

Table 3 Type of Cooking Fuels by Various Categories

	IHDS			IHEED		
	Clean Only	Biomass & Clean	Biomass Only	Clean Only	Biomass & Clean	Biomass Only
By Urban and Rural						
Rural	6%	38%	55%	9%	32%	60%
Urban	65%	24%	11%	42%	29%	29%
By Caste/Religion						
Brahmin	48%	30%	22%	38%	38%	25%
High Caste	40%	32%	28%	20%	40%	40%
Other Backward Castes (OBC)	20%	35%	45%	17%	41%	43%
Scheduled Castes (SC)	13%	34%	53%	16%	21%	64%
Scheduled Tribes (ST)	11%	35%	54%	25%	21%	51%
Muslim	19%	35%	46%	13%	44%	44%
Other	38%	50%	12%	67%	33%	0%
By Assets Quintile						
1st	2%	29%	70%	5%	12%	83%
2nd	6%	34%	61%	14%	26%	60%
3rd	15%	40%	45%	15%	34%	52%
4th	36%	41%	23%	26%	40%	34%
5th	64%	30%	6%	45%	42%	12%

Table 5 Basic Statistics of PM 2.5 Concentrations (mg/m^3)

	Mean	Std. Dev.	Min	Max
95^{th} Percentile PM 2.5 in Kitchen	2.98	5.36	0.02	56.60
95^{th} Percentile PM 2.5 in Living Area	0.85	0.74	0.02	17.18
Mean PM 2.5 in Kitchen	0.91	2.28	0.02	27.58
Mean PM 2.5 in Living Area	0.28	0.74	0.02	10.10

Table 4 Regression Results on Likelihood of Using Only Cooking Fuels

	Full Sample (1)	Rural Sample (2)
Economic Status - Asset Level	4.51	3.90
	[30.00]**	[21.32]**
Urban	1.30	
	[27.54]**	
Knowledge of harmfulness of smoke	0.00	-0.05
	[-0.09]	[-1.11]
Access to Electricity	0.50	0.52
	[11.00]**	[10.17]**
Access to Piped water	0.22	0.11
	[5.53]**	[2.21]*
Highest adult male education	0.02	0.02
	[4.88]**	[2.99]**
Highest adult female education	0.05	0.04
	[9.79]**	[6.71]**
Brahmin	0.21	0.25
	[2.18]*	[2.25]*
OBC	-0.24	-0.23
	[-4.67]**	[-3.94]**
Scheduled Castes	-0.31	-0.29
	[-5.44]**	[-4.29]**
Scheduled Tribes	-0.38	-0.31
	[-5.13]**	[-3.83]**
Muslim	-0.24	-0.04
	[-3.42]**	[-0.53]
Other- Sikh, Christian, Jain	0.48	0.54
	[3.99]**	[3.20]**
Owns a business	0.10	0.91
	[2.38]*	[1.75]
Any owned or cultivated farm	-0.30	-0.23
	[-7.56]**	[-5.18]**
Number of people in the household	-0.06	-0.09
	[-8.20]**	[-3.04]**
Economic index		0.03
		[2.75]**
Social infrastructure index		0.02
		[2.20]*
Public programs index		0.02
		[3.43]**
Pseudo R2	0.31	0.19
Observations	33220	18594

Robust z statistics in brackets
* significant at 5%; ** significant at 1%

Table 6 Regression Results of 95TH Percentile of PM 2.5 Concentrations in Kitchen

	Full Sample	Excluding PM2.5>20 mg/m3
	(1)	(2)
Only use clean cooking fuel	-0.39	-0.39
	[1.27]	[1.30]
Use both clean cooking fuel and biomass cooking fuel	-0.23	-0.25
	[1.32]	[1.49]
Mud wall	0.41	0.34
	[2.29]*	[1.93]
Have one vent or more	-0.15	-0.22
	[0.78]	[1.19]
Stove is in a separate kitchen with an inside entrance	-0.25	-0.19
	[1.06]	[0.80]
Stove is in an enclosed kitchen	-0.29	-0.26
	[1.34]	[1.21]
Stove is in a separate kitchen with both inside and outside entrances	-0.54	-0.50
	[2.25]*	[2.15]*
stove is outside	-0.14	-0.14
	[0.56]	[0.56]
Traditional chulha	0.34	0.36
	[1.51]	[1.58]
Improved chulha	-0.87	-0.74
	[1.42]	[1.23]
hara	1.29	1.42
	[1.68]	[1.91]
Stove using clean fuel	-0.86	-0.80
	[2.74]**	[2.60]**
Cooking time	0.09	0.10
	[1.63]	[1.72]
Number of people in the household	0.07	0.08
	[2.16]*	[2.50]*
Median temperature	0.04	0.03
	[1.65]	[1.14]
Median humidity	-0.01	-0.01
	[0.75]	[0.75]
West Bengal	-0.48	-0.33
	[1.45]	[0.99]
Madhya Pradesh	-0.63	-0.53
	[2.72]**	[2.29]*
R-squared	0.28	0.28
Observations	417	411

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

Table 7.Characteristics of the National Programme on Improved Chulhas in India Compared to International Experience

International practices in stove dissemination	*National Programme on Improved Chulhas practices*
Focus on need-based users	Target approach, stress on number of villages to be covered rather than households. Demand for stoves is not taken into consideration.
Minimal subsidy for the stove from government or donors	Subsidy on stove accounts for the largest share (50%) of government support. Users in periurban areas are willing to pay greater amounts subject to guarantee on stove quality
Maximum support for R&D, production and distribution of stoves, credit, capacity building and publicity awareness	Program funds technical backup units, but inadequate support given for R&D, with no such support extended to NGOs. Support for capacity and awareness generation not adequate.
Close interaction among the designers, producers and users of stoves	Adequate interaction between producer and user, but negligible between designer, and producer and user
Dependence on centralized production of stove and stove parts to enable out-reach to larger number of people due to lower cost of supply	For fixed stoves, there is no scope of centralized production as these are built at user's homes. Mass production of stove parts (chimney, cowl, etc) undertaken by private manufacturer. No mass production of the firebox.
Onus on producers and designers to meet needs of consumers	Consumer needs met by self employed workers/NGOs through changes in stove design with low inputs from designers
Long-term funding	Long-term target-based funding by government, routed through nodal agencies and disbursed through NGOs for implementation

Figure 1 PM 2.5 Concentrations (mg/m^3) in Kitchen and Living Area

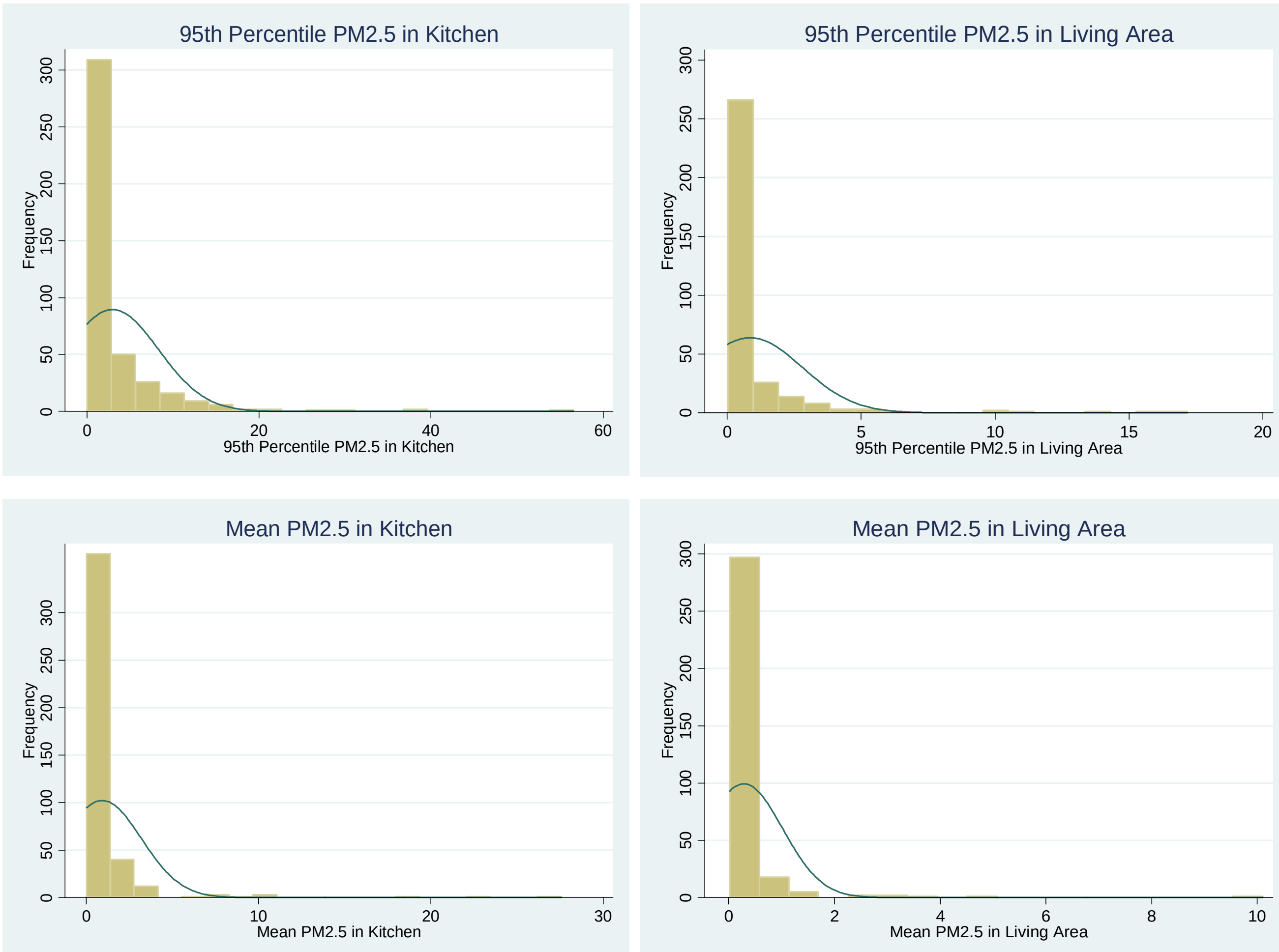
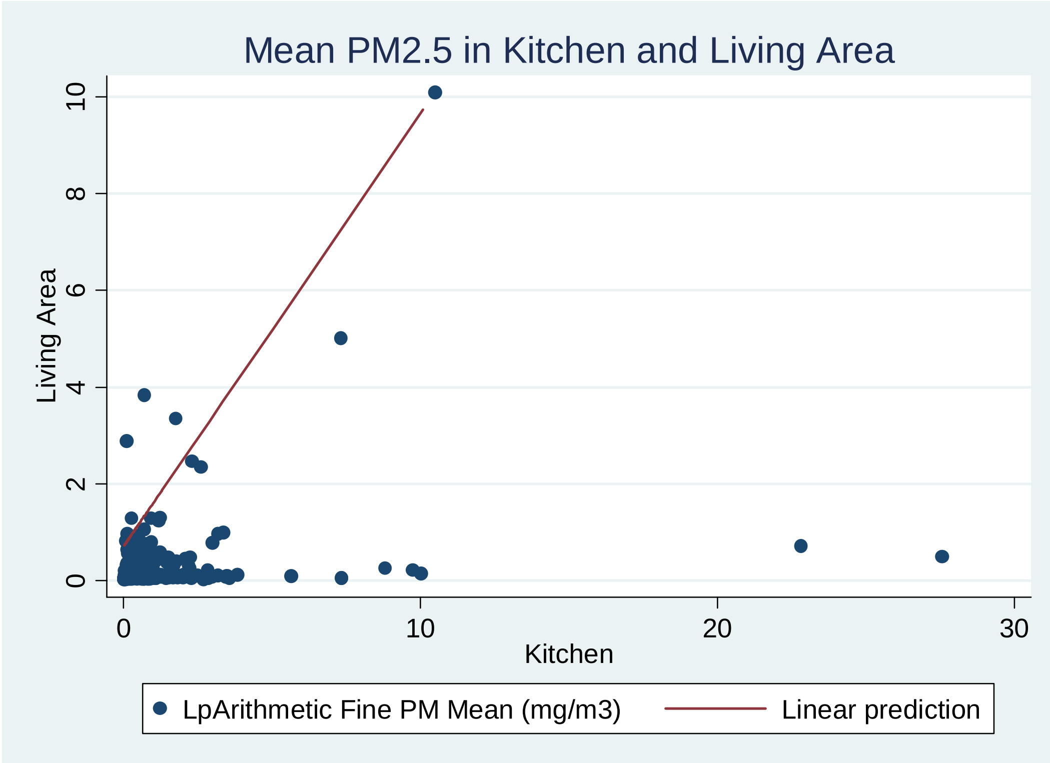
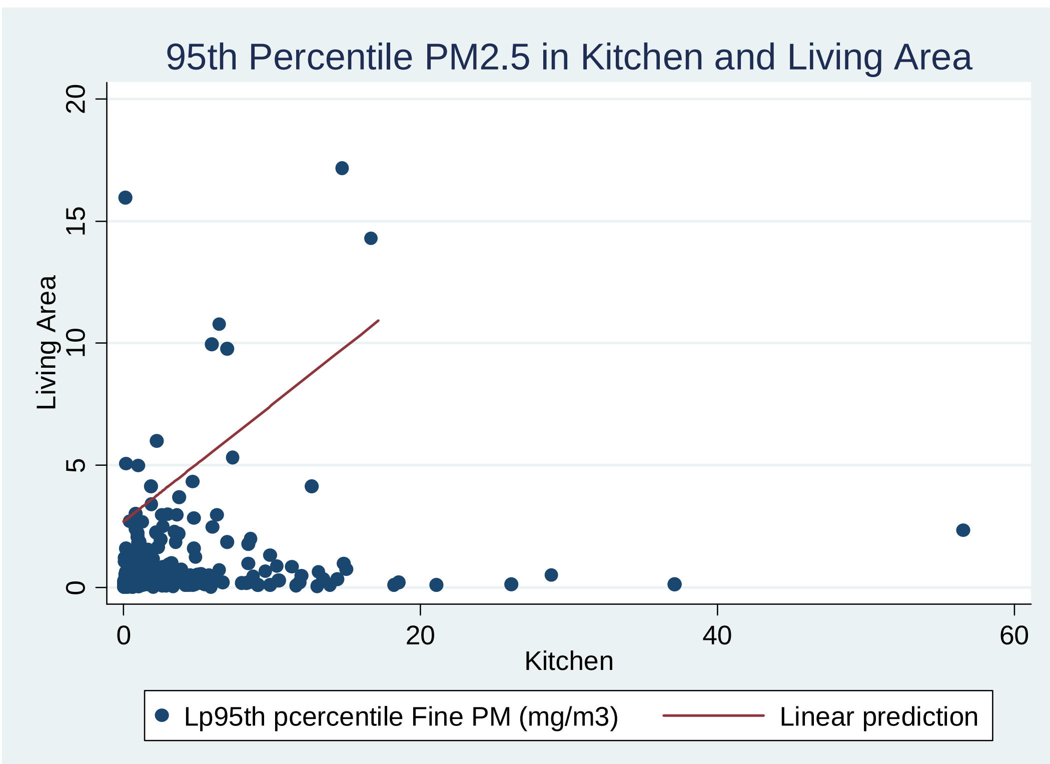


Figure 2 Mean PM 2.5 concentration levels in Kitchen and Living Area



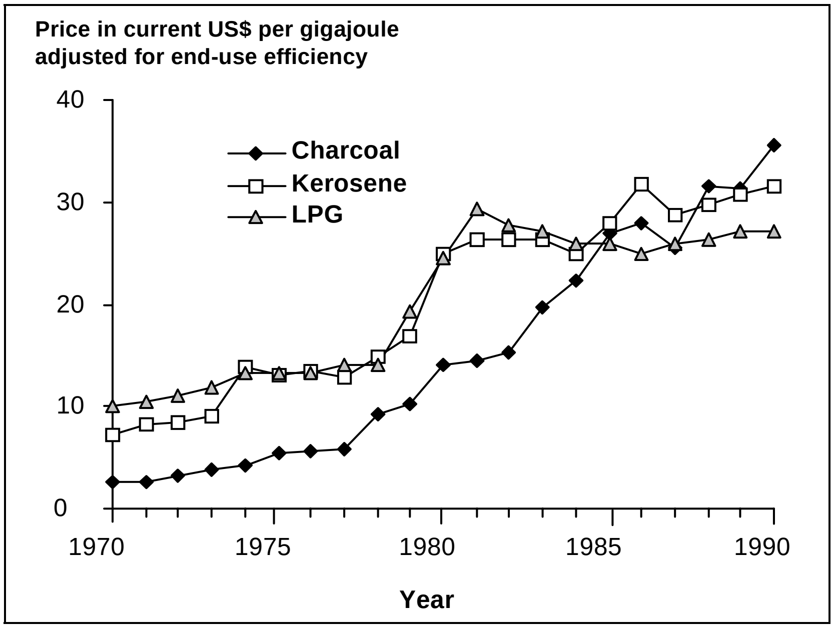
Correlation=0.27

Figure 3 Mean PM 2.5 concentration levels in Kitchen and Living Area



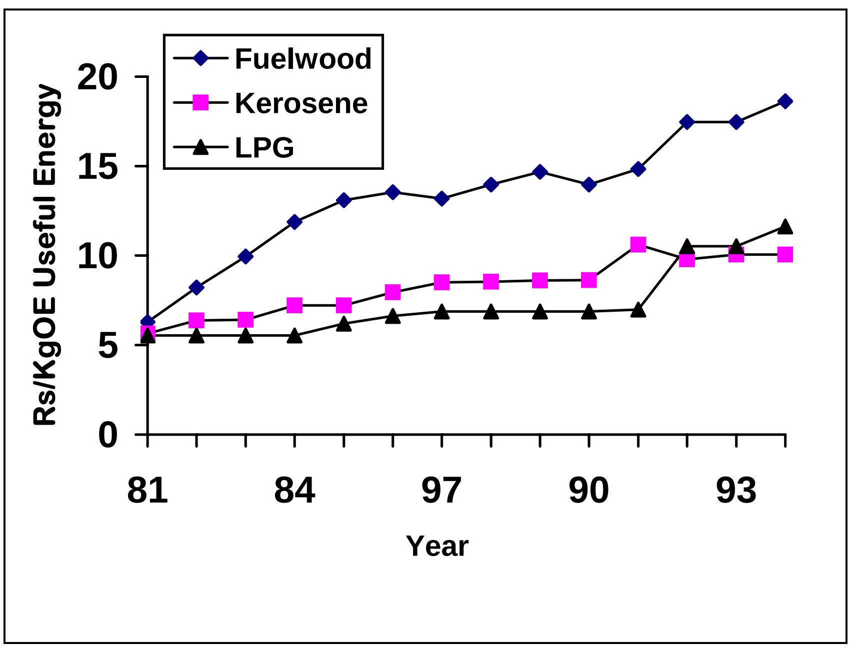
Correlation=0.16

Figure 4 Energy Prices in Haiti, 1970–90



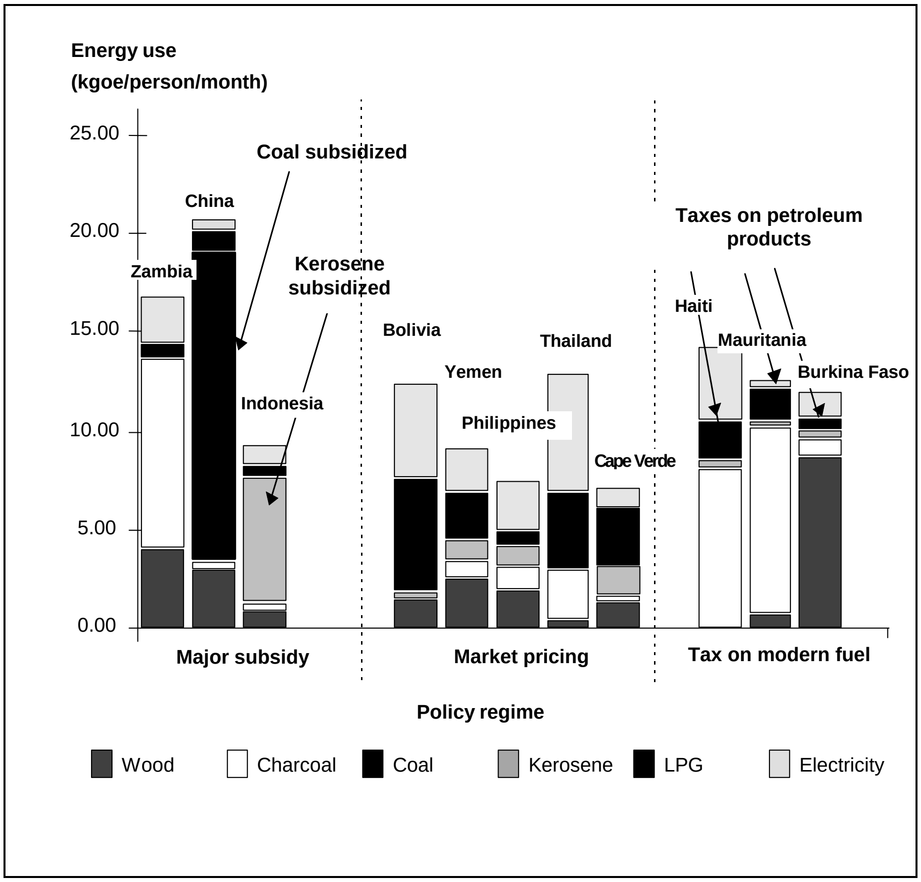
Source: World Bank (1991c). (IN urban energy transition)

Figure 5 Useful Energy Price of Cooking Fuels, Hyderabad, 1981-94 (Rs. Per KgOE of cooking energy)



Note: Fuel price trends have been adjusted for end use efficiency.
Source: Hyderabad survey data, 1994.

Figure 6: Energy Use and Government Policy



Source: Barnes, 2005

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