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Cooking Stoves, Indoor Air Pollution and Respiratory Health in Rural Orissa

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Indoor air pollution emitted from traditional fuels and cooking stoves is a potentially large health threat in rural regions. This paper reports the results of a survey of traditional stove ownership and health among 2,400 households in rural Orissa. We find a very high incidence of respiratory illness. About one-third of the adults and half of the children in the survey had experienced symptoms of respiratory illness in the 30 days preceding the survey, with 10 per cent of adults and 20 per cent of children experiencing a serious cough. We find a high correlation between using a traditional stove and having symptoms of respiratory illness. We cannot, however, rule out the possibility that the high level of observed respiratory illness is due to other factors that also contribute to a household's decision to use a traditional stove, such as poverty, health preferences and the bargaining power of women in the household.

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Over 72 per cent of all households in India and 90 per cent of households in the country's poorer, rural areas use traditional solid fuels, such as crop residue, cow-dung and firewood, to meet their cooking needs [Census of India 2001]. The burning of solid fuels indoors in open fires or traditional cooking stoves ('chulhas') results in high levels of toxic pollutants in the kitchen area. As such, the use of these fuels is considered a major risk factor for lung cancer as well as cardiovascular and respiratory disease [WHO 2002]. This paper reports on a new survey – in a rural area of the state of Orissa – that was designed to increase understanding of what types of households use traditional cooking fuels and to understand the correlations among fuel use, pollution levels and respiratory health.

The available evidence suggests that the indoor air pollution (IAP) from biomass fuels and traditional cooking stoves may be a serious health threat, particularly to women and young children who spend a considerable amount of time near the cooking stove. The smoke from burning solid fuels produces many pollutants, including particulate matter (PM) and carbon monoxide (CO) that have been shown to be highly toxic in animal studies and associated with increased rates of infant mortality [Chay and Greenstone 2003a and 2003b].[1] The emissions rates of pollutants from traditional stoves are extremely high. For example, Smith (2000) reports that mean 24-hour PM_{10} concentration from solid-fuel-using households in India sometimes exceeds 2,000 $\mu g/m^3$, where PM_{10} refers to particulate matter with a diameter of less than or equal to $10\mu m$; these particles are widely believed to pose the greatest health problems. By comparison, the United States (US) Environmental Protection Agency's (EPA) standard for an acceptable annual 24-hour average of PM_{10} in the US is 50 micrograms per cubic metre ($\mu g/m^3$) [EPA 2006]. The reported concentrations in India also look extremely high when compared to the EPA's other PM_{10} standard, which deems more than one exceedance per year of 150 $\mu g/m^3$ in a 24-hour period to be unacceptable.

What does this mean for public health? The *World Health Report 2002* of the WHO estimates that the percentage of the national burden of disease due to solid fuel use is 3.5 per cent in India. Exposure to indoor air pollutants is a major risk factor for chronic obstructive pulmonary disease (COPD) in adults and acute lower respiratory infections (ARI) among young children [WHO 2002]. It is estimated that indoor air pollution accounts for one-third of ARI cases and that ARI accounts for up to 20 per cent of deaths among children under the age of five. This means that, after contaminated water, solid fuels – used by over half of the world's population – are the most important environmental cause of disease [Bruce et al 2006].

Despite the importance of impact of IAP on the health of women and children, there is very little systematic evidence on the usage patterns of traditional cooking fuels and stoves in India. There is even less reliable field survey data on either the associations between traditional cooking fuels and stoves and respiratory health or the causal effects of cleaner stoves on health. This paper reports on our attempt to fill these important gaps in the literature. We analyse data from the largest field survey of stove use and respiratory health ever carried out in India.

1 The Chulha Survey

The survey, conducted between January and July 2006, is a joint collaboration by the non-governmental organisation (NGO) Gram Vikas and the Chennai-based Centre for Microfinance at the Institute for Financial Management and Research (CMF).[2] It covered 2,357 households across 40 villages in the districts of Ganjam and Gajapati in Orissa. The sample was drawn from the villages in which Gram Vikas operates. In this respect, it is not strictly representative of all of India. However, to the extent that the households surveyed are rural and poor, it is representative of the typical users of traditional fuels in India. To our knowledge, this dataset is the largest and most comprehensive one available, combining a high-quality household socio-economic survey; a physical check-up; recall-based health data; reliable information on stove availability, stove use and fuel consumption; and economic productivity and well-being data for children and adults.

The survey consisted of three modules, consecutively administered on each household visit. First, the CMF field officers administered the comprehensive household survey, which covered household composition (size and members' ages, sexes, and relationships to the head), demographics (education levels, caste, religion), economics (income flows, indebtedness, wealth) and consumption (particularly related to health and fuel). The questions on wealth and income mimic the National Sample Survey of India – a nationally representative survey conducted every five years – allowing us to see where the sampled households fall in the income distribution of rural India. To assess household exposure to indoor air pollution, the survey also covered stove ownership by type, stove use, housing construction and fuel use.

Next, CMF field officers interviewed each household member individually (for children aged 14 and below, the child's primary care-giver completed the child survey). The interviews covered the individual's exposure to stoves, including stove type, duration of exposure and frequency. Questions included the number of meals the individual cooked that week, time spent cooking and time spent near the stove. Next, CMF field officers collected data on the self-reported health status of each survey respondent. Respondents were asked a series of recall questions on symptoms experienced in the last 30 days (coughs or flu, cough with blood, etc) and the severity of the symptoms. To further gauge respiratory function, respondents were asked how difficult it was for them to perform common activities (work in the field for one day, walk 200 metres, walk five kilometres, draw water from a well, climb a small hill, lift or carry heavy objects such as a 5-kg bag, etc). Finally, to gauge the productivity effects of respiratory heath, CMF collected data on school attendance for children and employment status and time-use patterns for adults over the last 24 hours.

After the survey, the field officers administered a short physical health examination in order to develop a richer portrait of the respondent's general and respiratory health status. They obtained biometric data (height, weight and arm circumference) and then conducted two tests designed to gauge actual respiratory functioning and exposure to smoke. First, following the RESPIRE study in Guatemala [Smith et al 2006], CMF measured CO in exhaled breath with a micro medical CO monitor. The presence of CO in breath is a biomarker of recent exposure to air pollution from biomass fuel combustion, making it a good proxy for individual exposure to smoke from cooking stoves in rural settings where there are few other sources, such as combustion in vehicle engines or industry. Second, the field officers conducted a spirometry test, which is designed to gauge respiratory health by measuring how much air the lungs can hold and how well the respiratory system can move air in and out of the lungs. The tests were conducted using guidelines from the American Association for Respiratory Care. The following measures were recorded: (1) FEV1, the forced expiratory volume in the first second; (2) FVC, the forced vital capacity; (3) PEF, the peak expiratory flow; (4) MMEF, the maximum midexpiratory flow; and (5) FEV1 per cent, the FEV1 expressed as a percentage of the total volume. Each individual was tested up to seven times, until at least two FEV1 readings were within 100mls (or 5 per cent) of each other. In contrast to peak flow tests, spirometry readings can be used to diagnose obstructive lung disorders (such as COPD and asthma) and restrictive lung disorders. Further, they provide the only measurements of lung function that are comparable across individuals [Beers, Berkow et al 1999].

2 Demographics and Household Stove Use

Table 1 presents the basic statistics on demographics from the sample. Households in the study tend to be quite disadvantaged. Per capita consumption is roughly Rs 500 per month, with about one-third of households living on less than $1 per day (in per capita at purchasing power parity). Only half of the households have electricity and a similar fraction have a literate head of household. A large percentage of households come from the traditionally disadvantaged minority groups of India: about a quarter of households belong to the scheduled caste and a little over 10 per cent belong to the tribal communities.

Table 1: Household Demographics

Monthly per capita expenditure	495.71
Head of household literate	51.9%
Household has electricity	46.9%
Scheduled caste	27.0%
Scheduled tribe	12.6%

In Table 2 (p 73), we provide sample statistics on household stove use. Column 1 provides these statistics for the full sample, while columns 2 and 3 provide these statistics for those above and below the median income in the sample (Rs 400), respectively. Households typically cook 14 meals a week (about two meals a day), regardless of their income status. To cook these meals, most households – about 94 per cent – use a traditional stove with biomass fuel as their primary cooking stove. Almost always, the stove is constructed of mud and tends to have space for one pot. The stoves are often located in a kitchen area with little or no ventilation.[3] Heavy black smoke stains surrounding the opening of the stove and on the walls – hinting at the level of pollutants the household members breathe in as a result of the stove.

Table 2: Stove Types, for All Households and by Income

	All Households (1)	Above Median PCE (2)	Below Median PCE (3)
Number of meals per week	14.18	14.26	14.09
Household primarily uses "dirty stove"(%)	93.6	91.4	95.6
Per cent of households that own:			
LPG stove (%)	4.6	7.0	2.3
Electric stove (%)	11.4	16.2	6.6
Biogas stove (%)	3.2	3.1	3.4

Median monthly per capita income (PCE) in the sample is Rs 401.61.

Table 3: Which Types of Households Use Clean Stoves?

	(1)	(2)
Constant	-0.0555	-0.0513
	(0.0132)***	(0.0162)***
Household has electricity	0.1043	0.0901
	(0.0111)***	(0.0121)***
Head of household literate	0.031	0.0288
	(0.0103)***	(0.0102)***
Log (monthly per capita expenditure)	0.0001	0.0001
	(0.0000)***	(0.0000)***
Scheduled caste	0.0208	0.0344
	(0.0124)*	(0.0366)
Scheduled tribe	0.0002	0.0283
	(0.0162)	(0.0227)
Women in household has savings account	0.0283	0.0207
	(0.0080)***	(0.0081)**
Cigarette smoker in household	-0.0025	0.0092
	(0.0140)	(0.0138)
Village fixed effects		X
Observations	2220	2220
R-squared	0.08	0.16

Standard errors in parentheses below coefficient estimates.

Richer households are slightly less likely to use a dirty stove as a primary stove (91.4 per cent versus 95.6 per cent). While this difference is not large, it is statistically significant at the 1 per cent level. A small percentage of households do own stoves that use cleaner fuels: 4.6 per cent of households own a liquefied petroleum gas (LPG) stove, 11.4 per cent own an electric stove and 3.2 per cent own a biogas stove. Richer households are also more likely to own stoves that use cleaner technologies, with about 7 per cent and 16.2 per cent of those above median per capita expenditure owning LPG and electric stoves, respectively, as compared to 2.3 per cent and 6.6 per cent of those below median. Note, however, that households typically own different types of stoves at the same time, so those that own clean stoves may not necessarily use them. For example, about 60 per cent of households that owned a clean stove still used a traditional stove as their primary cooking stove in the week prior to the survey. This is likely due to the high marginal costs of using cleaner fuels.

These data on stoves naturally raise the question of which types of households use clean stoves. Table 3 answers this question by reporting the results of linear regressions of the probability that a household uses a clean stove as their primary stove in week before the survey. Each row presents the parameter estimates for the indicated variable and standard errors (in parentheses). In columns 1 and 2, we present results from specifications with and without village fixed effects, respectively.

As in Table 2, the results here show that the higher a household's income, the higher its probability of using a clean stove. Controlling for income, households with electricity are more likely to use a clean stove. This is not surprising since, with 11.4 per cent ownership, electric stoves are the most common type of clean stove. Notably, households in which women may be more empowered – by virtue of being members of a savings group – are 2 to 3 per cent more likely to use a clean stove; however, this could also be the result of unobserved differences in household wealth or income. We do not find any significant differences in the probability of stove usage by caste. All in all, Table 3 clearly shows that stove use is correlated with a number of household characteristics that are also correlated with health, including female empowerment and income.

3 Individual Stove Exposure and Health

This section looks in detail at the impact on health of individual stove exposure.

3.1 Adult Cooking Patterns and Health

Figure 1 shows the per cent of individuals that cooked at least once in the past five days, by gender. As expected, the responsibility for cooking falls primarily on women: 68 per cent of women had cooked at least once in the five days preceding the interview, compared to only 6 per cent of men. Even conditional on having cooked a meal, women tend to cook more: women had cooked 11 meals per week while men had cooked only six meals per week (Figure 2). Excepting the mothers of the household head – only 20 per cent of whom had cooked in the five days preceding the survey – the majority of the women had cooked at least once in the previous five days, regardless of their role in the household (Figure 3).

Figure 1: Who Cooked at Least Once in the Last Five Days, by Gender (in %)

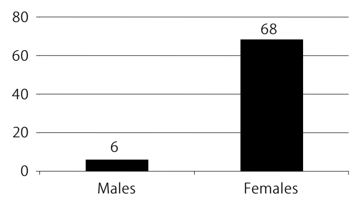

Figure 2: Number of Meals Cooked in the Last Week if Cooked, by Gender

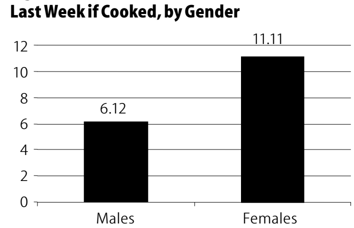

Figure 3: Who Cooked At Least Once in the Last Five Days, by Relationship to Head of Household (Adult Females Only, in %)

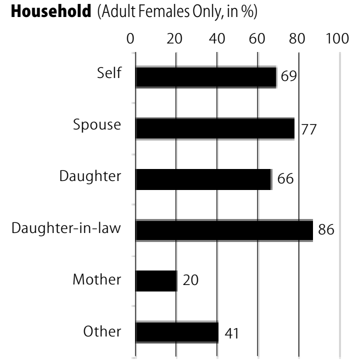

Table 4 (p 74) shows the health status of adults, based on both subjective self-reported measures and objective measures from the on-the-spot physical exam. Column 1 presents the statistics for males; column 2 for females; and columns 3 and 4 for females disaggregated by whether or not they cooked at least once in the last week. We first present results on general health – namely, average height and body mass index (BMI). Height is often seen as an indicator of long-run health and nutritional status, while BMI is an indicator of short-run health and nutritional status. Both indicators suggest that this study population tends to be in poor overall health. Males in the sample are roughly 160 cm in height (below the Indian average of 167). On average, males in the sample have a BMI of 19.62. A person with BMI less than 19 is classified as malnourished; about half of the males in this sample fall into this category. The women in the sample tend to be shorter (about 151 cm) and also have a low BMI average of approximately 19.

Table 4: Health Status of Adults

	Males (1)	Females: All (2)	Females: Cooked At Least Once in the Last Week (3)	Females: Did Not Cook at All in the Last Week (4)
Height	161.97	150.88	151.28	150.50
BMI	19.62	19.39	19.12	20.23
Cough in the last 30 days	0.33	0.31	0.31	0.32
Cough last more than two weeks	0.09	0.09	0.08	0.10
Cold or flu in the last 30 days	0.43	0.45	0.45	0.44
Cold or flu last more than two weeks	0.10	0.10	0.10	0.09
Activity index	0.49	0.89	0.81	1.96
% with CO reading above 6 ppm	0.52	0.44	0.45	0.40
% with CO reading above 10 ppm	0.33	0.21	0.21	0.19
FEV1/FVC	0.83	0.85	0.86	0.84
FEV1/predicted FEV1	0.70	0.69	0.69	0.69
Obstructive respiratory disease	0.12	0.10	0.09	0.12
Moderate to severe restrictive respiratory disease	0.14	0.14	0.13	0.19

The self-reported health data indicate a substantially high prevalence of respiratory disease in both males and females. About one-third of all males had a cough in the last 30 days, with 9 per cent of all males (or about one-third of those who had a cough) stating that they had a cough that lasted more than two weeks. Forty-three per cent of all males had a cold or flu in the last 30 days, with 10 per cent of all males stating that they had a cold or flu that lasted more than two weeks. The incidence rates are virtually identical for women, regardless of whether or not they had participated in cooking activities in the last five days. These self-reported replies to the health questions reflect genuine health problems because households report that they devote roughly 17 per cent of their consumption expenditures to healthcare. While this number seems high, a survey of a poor population in the state of Rajasthan also found a high ratio of health expenditures to overall expenditures [Banerjee, Deaton, Duflo 2004].

The activity index measures the number of activities the individual indicated he or she would be unable to do or unable to do without help (self-reported). Activities include: work in the field for one day, walk 200 metres, walk five kilometres, draw water from a well, climb a small hill, lift or carry heavy objects (for example, a 5-kg bag), routine housework such as cleaning or cooking, stand up from sitting on the floor, bow, squat or kneel, routine daily activities (dressing, bathing or using the toilet) and routine housework such as cleaning or cooking. All responses were entirely self-reported – the respondents were not asked to demonstrate their ability or inability to perform them. As such, the activity index is a good measure of the respondent's perception of his or her own health. This may be important since other household members' perceptions of how healthy an individual is could be a factor in their allocation of household healthcare consumption and of housework – some of which increases exposure to pollutants.

Women have a higher activity index than men, indicating that they report having more difficulties performing these basic physical activities. Women who do not cook have the highest activity index, suggesting that women who report being indisposed to physical activity are given leave from household responsibilities. This is supported by the fact that women who do not cook tend to be older (on average, they tend to be 11 years older than women who cook) and tend to be the mother of the head of the household.

Table 4 also shows the objective measure of CO exposure and respiratory health taken during the physical examination. The CO breath test used measures the concentration in parts per million (ppm) of CO in the lung alveolar – a good proxy for exposure to IAP. In the absence of high exposure to IAP, concentrations in the range of 0 to 6 ppm would indicate that the person is a non-smoker, while 7 to 10 ppm, 11 to 20 ppm, and greater than 20 ppm would indicate that the person is a light, regular or heavy smoker, respectively [Jarvis et al 1980; Jarvis et al 1986]. Men had higher CO breath test readings than the women: 52 per cent of men had CO readings above 6 and 33 per cent had readings above 10; for women these figures were 44 and 21 per cent, respectively. Since women spend more time cooking than men, we would expect the women to show higher smoke exposure. However, men's higher exposure to smoke could be due to the higher prevalence of tobacco smoking among men; we could not, however, determine whether this was true, as few individuals in the survey admitted to smoking cigarettes or beedis.

Among the women, those who do not cook have lower smoke exposure than those who do: 45 per cent of women who cook regularly had a CO reading greater than six, compared to 40 per cent of those who do not cook. This difference is significant at the 1 per cent level. While this could be due to the fact that women who do not cook spend less time around the stove, there could also be alternative explanations: women who do not cook may be less physically able (as indicated by the activity index) and therefore, choose to smoke less.

Finally, Table 4 shows the results of the spirometry test, which measure individuals' respiratory function. The FEV1 is the volume of air expelled in the first second of a forced expiration starting from full inspiration and the FVC is the maximum volume of air in liters that can be forcibly and rapidly exhaled. The FEV1/FVC is the ratio of the two measures. The average FEV1/FVC was 83 per cent for men and 85 per cent for women. These values are similar to the 85.78 per cent reported in a recent study in Guatemala [Smith et al 2006].

The results of the spirometer can be used to diagnose "obstructive respiratory disease" and "moderate to severe restrictive respiratory disease" [Mannio et al 2003; Barreiro and Perillo 2004]. A lower FEV1/predicted FEV1 (typically below 80 per cent) combined with a lower FEV1/FVC (typically below 70-75 per cent) indicates a higher probability of an obstructive respiratory disorder.[4] We find that about 12 per cent of males and 10 per cent of females can be classified as having obstructive respiratory disease. About 14 per cent of the population would be classified as having moderate to severe restrictive respiratory disease.[5] Interestingly, though, women who did not cook in the last week have a higher probability of experiencing moderate to severe restrictive respiratory disease.

3.2 Child Health

Table 5 reports on children aged 14 and under. It is evident that the incidence of respiratory symptoms is also high among them: 50 per cent of all children had a cough in the last 30 days and 40 per cent of these (or 20 per cent of the sample) had had a serious cough. These illnesses translated into high healthcare expenditures: about 40 per cent of the children saw a healthcare provider in the last 30 days. Children aged 10 to 14 years were also give the CO breath test. About 37 per cent of these children had CO readings greater than 6 ppm and 18 per cent had readings greater than 10 ppm. Children's exposure to CO appeared to be lower than that of the adults but their CO readings were still extremely high for a group that includes very few smokers.

Table 5: Health Status of Children

Variable	Mean
BMI	19.19
Cough in the last 30 days	0.50
Serious cough in the last 30 days	0.21
% with healthcare visit in the last 30 days	0.42
% with CO reading above 6 ppm	0.37
% with CO reading above 10 ppm	0.18

3.3 Household Stove Use and Health

Table 6 presents suggestive evidence that indicates that clean stove use is associated with lower CO exposure and better health for women (panel A) and children (panel B). The table presents the results of a linear probability model, with the dependent variables noted in the row headings. We report the coefficient and associated standard error for an indicator variable for using a clean stove. We also report the mean of the dependent variable, the R-squared statistic and the number of observations. All regressions include controls for age, scheduled caste, number of household members, an indicator variable for landownership, household per capita expenditures, and gender (for the children). We additionally control for height and weight in columns 1, 2 and 3 when the outcome of interest is obtained from the spirometry or CO breath tests. The regressions for adults also include an indicator variable for whether the individual is a self-reported smoker.

Table 6: Associations between Stove Use, CO Exposure and Health

	CO>6 (1)	CO>10 (2)	Obstructive Respiratory Disease (3)	Cold or Flu in the Last 30 Days (4)	Cough in the Last 30 Days (5)	Serious Cough (6)	Activity Index (7)
A Women							
Clean	-0.071	-0.06	-0.013	-0.085	-0.07	-0.032	-0.075
	(0.036)*	(0.027)**	(0.022)	(0.032)***	(0.028)**	(0.016)**	(0.101)
Mean	0.44	0.21	0.10	0.45	0.31	0.09	0.88
N	2859	2859	2673	3734	3733	3732	3736
R^2	0.00	0.00	0.03	0.01	0.02	0.02	0.26
B Children							
Clean	-0.088	-0.082			-0.094	-0.044	
	(0.065)	(0.044)*			(0.030)***	(0.023)*	
Mean	0.37	0.18			0.5	0.21	
N	713	713			4589	4588	
R^2	0.04	0.02			0.03	0.04	

(1) For women, a serious cough is defined as a cough lasting more than two weeks. For children, parents were asked whether the cough was "serious". (2) Activity Index measures the number of activities the individual indicated he would be unable to do or unable to do without help. Activities include: work in the field for one day, walk 200 metres, walk five kilometres, draw water from a well, climb a small hill, lift or carry heavy objects (e g, a 5-kg bag), routine housework such as cleaning or cooking, stand up from sitting on the floor, bow, squat or kneel, and routine daily activities such as dressing, bathing or using the toilet.

We find a strong negative correlation between using a clean stove and having a high CO reading. Using a clean stove is associated with a 7 percentage-point decrease in the probability of having a CO reading greater than 6. Given that about 44 per cent of women have a CO reading over 6, this corresponds to a 15 per cent difference (column 1). The results are larger for children under 14, with an 8 percentage-point or 23 per cent difference, but this difference is not statistically significant. Using a clean stove as the primary stove reduces the probability that a child has a CO reading above 10 by 8 percentage points. Given that 18 per cent of kids have a CO reading over 10, this corresponds to a 45 per cent difference (column 1).

There is little evidence that using a clean stove affects the probability of having an obstructive respiratory disease (column 3). However, we find that using a clean stove is associated with a lower probability of having a cold or flu in the last 30 days (column 4), of having a cough in the last 30 days (column 5) and of having a serious cough in the last 30 days (column 6). As shown in column 7, there is not a statistically significant relationship between using a clean stove and the activity index.

Of course, these correlations between stove use and CO exposure and health status do not indicate a causal effect of clean stoves: households that use a clean stove may also be healthier because they are richer (recall Table 2) or more health-conscious. Nevertheless, the findings in this section indicate that there is substantial scope for improvement in the respiratory health status of these households and that reducing CO exposure through the introduction of clean stoves might be an effective channel to achieve this improvement.

4 Conclusions and Future Research

Our survey provides evidence on stove use and health in Orissa. We show that indoor air pollution is indeed a significant health threat in rural areas where households rely on traditional chulhas for their cooking needs. We find a high incidence of respiratory illness: about one-third of all adults and half of all children experienced symptoms of respiratory illness in the 30 days prior to the survey, with 10 per cent of adults and 20 per cent of children experiencing a serious cough.

There is a strong correlation between using a stove with cleaner fuels and having better respiratory health, suggesting that the use of traditional stoves may indeed be a culprit behind these high levels of respiratory disease. However, because the choice of stove use is correlated with other factors that affect health (such as income levels and empowerment of women), we cannot fully disentangle the effect of using a clean stove from the effect of being the type of household that would use a clean stove. Thus, observational studies are likely to confound the impacts of clean stoves on health outcomes with these and other determinants of health and well-being.

Future research will help to distinguish between these two effects. In the same region covered by this baseline survey, Gram Vikas is randomly assigning improved cooking stoves to households. The improved cooking stoves include a chimney that when used properly should reduce IAP within the household. Gram Vikas and CMF will conduct follow-up studies to determine whether the improved stoves reduce smoke exposure (as measured by the CO analyser) and improve respiratory health.

Since the stoves will be randomly phased in, households that obtain a stove at the start of the programme will be statistically indistinguishable from those that obtained the stoves at the end. Thus, any difference in outcomes can be attributed solely to the improved cooking stoves. This research will provide more information on the consequences of IAP exposure. Further, it will provide insights into improved cooking stove programmes that can help guide the activities of NGOs working in rural India and elsewhere.

NOTES

1 Particulate matter is a mixture of solid and liquid particles of organic and inorganic substances suspended in air. Particles are classified according to their diameter in micrometers; PM_{10} designates particles with diameters of 10 micrometres or less, while $PM_{2.5}$ designates diameters of 2.5 micrometres or less. The smaller the diameter, the greater the risk; finer particles can be inhaled deeper into the lungs, causing greater damage to respiratory function. CO is a highly poisonous gas found in combustion fumes, such as those produced when burning solid fuels. CO can build up in enclosed poorly ventilated spaces. CO compromises the transportation of oxygen by the red blood cells, which can lead to tissue damage and death.

2 Gram Vikas is a registered NGO under the Societies Registration Act of 1960 and is currently serving a population of more than 28,000 households across 400 villages. Gram Vikas' housing and environmental work have received international recognition (including the World Habitat Award 2003 for the Rural Health and Environment Programme awarded by the Building and Social Housing Foundation, UK; Most Innovative Project Award 2001 from the Global Development Network of the World Bank for the Rural Health and Environment Programme; and The Kyoto World Water Grand Prize 2006 for their contribution to address the critical water needs of communities). More information about Gram Vikas is available at: http://www.gramvikas.org/.

3 While some households also may construct a stove outside the main housing structure, they typically also have an inside stove for the monsoon seasons.

4 Predicted value formulas for FEV1 were taken from Crapo et al (1981). The formulas are as follows:

FEV1 = 0.1052*Height(inches) – 0.0244*Age(years) – 2.1900 [Men]

FEV1 = 0.0869*Height(inches) – 0.0255*Age(years) – 1.5780 [Women]

5 However, these diagnoses must be made with caution. Recent work suggests that the predicted value formulas and cut-offs used to diagnose the respiratory disorders may be inappropriate for Indian populations.

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