Sharing the Burden of Disease:
Gender, the Household Division of Labor and the Health Effects of Indoor Air Pollution in Bangladesh and India

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Abstract

In many rural areas of low-income countries, biomass fuel is the principal source of household energy so that indoor air pollution (IAP) is a serious health problem. If exposure to IAP is greatest in areas where combustion occurs, primarily the kitchen, IAP will mostly affect the women who cook and the children whom they supervise. Using a 2000-2003 survey of 1,638 rural households in Bangladesh, where biomass fuel provides more than 90 percent of household energy, and a 1999 national survey of 7,734 rural households in India we investigate (i) the extent to which the division of household responsibilities, household structure, nutritional intake, dimensions and location of kitchen facilities, and fuel and stove types causally affect the health of women and children, taking into account heterogeneity among household members and optimizing behavior within households, and (b) whether households act as if they are optimally sharing the burden of a disease. The results suggest that proximity to stoves adversely affects the respiratory health of women and the young children they supervise and that households appear to be aware of and attempt to mitigate the health effects of cooking with biomass fuels in their time allocation decisions, including effects on young children, such that women with lower endowed health have greater exposure to smoke and women with very young children have less exposure to pollutants. We also find, however, that due to measurement error, conventional estimates of the impact of smoke inhalation are underestimated substantially but that neglect of nutritional intake in prior studies is not a major source of bias. Finally, our results suggest that improving ventilation by increasing the permeability of roofs or walls has no significant effect on health, consistent with prior studies examining point-source pollutants and health data. However, chimneys can evidently significantly reduce the health impacts of stove proximity when biomass fuels are used.

I. Introduction

In assessing the determinants of poor health and mortality in developing countries, an important factor that has recently gained prominence is the magnitude of the health loss associated with exposure to indoor air pollution (IAP) in poor rural households. Approximately one half of the world's population relies on biomass and coal as their primary source of household energy. Biomass fuel, such as wood, crop refuse, and dung, accounts for one half of household energy in many developing countries, and for as much as 95% in some lower income ones, such as rural Bangladesh (Biswas and Lucas, 1997). Indoor air pollution is thus considered a serious health problem in low-income settings. Exposure to IAP from the combustion of solid fuels has been associated, with varying degrees of evidence, as a cause of several diseases including acute respiratory infections (ARI), chronic obstructive pulmonary disease (COPD), asthma, diseases of the eye such as cataract and blindness, and low birth weight and associated neonatal conditions (as a result of maternal exposure during pregnancy). ARI accounts for 6 percent of worldwide disease and mortality, mostly in the developing countries. Global mortality from IAP is conservatively estimated at 1.5 million to 2.0 million deaths in 2000.

ARI is also the most common cause of illness and mortality in children in the developing world, according to WHO's World Health Report. Acute lower respiratory infection, the most serious type of ARI, accounts for 20 percent of the annual deaths of children under five, with nearly all of these deaths occurring in the developing countries. Not only is IAP- induced ARI a leading cause of deaths in developing countries, but exposure during childhood can have long-term consequences. Lungs typically grow to full capacity during the teen years. The deficits in the lung function of children caused by air pollution are unlikely to be made up as children age even if their exposure levels decline dramatically, and the greatest effects of these pollution-related childhood deficits may occur later in life (Gauderman 2004).

Despite the importance of indoor air pollution as a determinant of health and its evident relationship to household decisions, little research has been carried out on it by economists addressing health issues in low-income settings. The comprehensive review of the literature on health and development by Strauss and Thomas (1998), for example, cites no studies on this topic, although economists have recently studied the effects of outdoor smoke arising from forest fires on health and child mortality (Frankenberg, McKee and Thomas (2005), Jayachandran (2005)). The existing evidence relating health to IAP, however, has a number of deficiencies. We distinguish two literatures. The *exposure assessment* literature associates pollutant measures taken at one or more places in the household by air monitoring equipment with attributes of the house such as ventilation, fuel type, and distance from cooking fire. The monitoring data available to exposure assessment studies has, until recently, come from air samplers that measure 24-hour average particulate concentrations. Recently, real-time monitors that record airborne respiratory particles less than 10 microns (PM_{10}) and 2.5 microns ($PM_{2.5}$) at 2-minute intervals for 24-hours have become available which allow investigators to associate pollutant levels with time of day as well as with attributes of the house. Two very recent World Bank working papers by Dasgupta *et al.* (2004a, 2004b) in Bangladesh are excellent examples of this literature. Using both 24-hour average and real-time (for a small sub-sample) particulate monitors, they present regression results for the effects of wall and roof permeability (thatching is the major source of permeability), fuel use, and location of the kitchen and its openness to the other rooms in the house, on household IAP. Their results highlight the importance of ventilation factors in the determination of PM_{10} concentrations. They find that the construction of walls and roofs have large and statistically significant effects on 24-hour average IAP concentration, as does whether the kitchen is located outdoors.

In the rural sample of Bangladeshi households, where LPG/LNG, piped natural gas, and kerosene are not used as cooking fuels, they find that different sources of biomass fuel contributes very little to explaining differences in measured average IAP, concluding that fuel choice is secondary to ventilation factors in explaining variation in IAP among Bangladeshi households. They suggest that an implication of their research for policy is that poor families need not wait for cleaner stoves or fuels to reduce IAP, but that instead inexpensive changes in ventilation or a simple reallocation of activities will result in significantly cleaner air. By inference, households are either unaware of or unwilling to make the modifications to attain these health gains. Indeed, in the second Dasgupta *et al.* (2004b, p. 14) paper, they suggest that "during peak cooking periods, simply moving the children outside when weather permits could yield significant health improvements." This research and these conclusions, however, are based on inferences about the relationship between air pollutants and health, and not based health measured in their samples.

In contrast, the *exposure response* literature directly relates data on the health outcomes of individuals to the measures of particulate exposure. In this literature, the importance of collecting **person-specific** information on exposure rather than information specific to various places in the house is stressed. This is analogous to the literature on the intra-household allocation of nutrients, which determines individual variation in health, and on which there is a relatively large literature (e.g., Behrman (1988) and the review in Behrman (1997)). In this case, however, relating individual health to average particulate concentrations in the home requires information on the intra-household allocation of time. Indeed, the evidence suggests that just as the household food-sharing rules are reflected in the distribution of health in the household, the allocation of time of household members determines how the burden of disease, induced by point-source pollution, is shared. Although an older literature in economics (e.g., Evenson (1978)) has examined the household allocation of time in low-income countries, that work never noted the health consequences of the division of household activities.

The work of Majid Ezzati and colleagues exemplifies the epidemiological literature on the health consequences of exposure to indoor pollutants based on indvidual-specific exposure and health measurement. In Ezzati, Saleh, and Kammen (2000) and Ezzati and Kammen (2001), personal monitors with real-time monitoring were employed, along with simultaneous recording of the locations and activities of household members, in order to construct personal exposure profiles for households in rural Kenya over a two-years period. The field measurements recorded peak concentrations of greater than 50,000 $\mu g/m^3$ (micrograms of particulate matter per cubic meter of air) in the immediate vicinity of the cooking fire with concentrations falling significantly with increasing distance from the fire. In a review of the limited studies examining the pollution "microenvironment," Ezzati and Kammen (2002, p. 1059) concludes that:

> Coupled with the large variability of emission from biofuels over short periods, with the instantaneous peaks coinciding with household members who cook being consistently closest to the fire, this [evidence] indicates that the complete time-activity budgets of individuals, in relation to emission concentrations, are important determinants of exposure.

In their Kenyan sample, Ezzati and Kammen (2001) find that one-half of the daily exposure of the highest exposure individuals - those individuals who cook - occurs in high-intensity episodes when they are very close to the stove when stove emissions are at their highest. High-intensity episodes contributed only 0% - 11% of the total exposure of household members who do not take part in cooking. In their statistical analysis, Ezzati and Kammen (2001) find that the relationship between ARI and exposure measured by average daily PM_{10} exposure and time spent indoors, without adjustment for the activities of individuals, mis-estimates the effect of exposure on the probability of a ARI diagnosis for women. Controlling for the time spent cooking, in one specification, and for high-intensity exposure in another, eliminated gender as a significant determinant of ARI, suggesting that gender was simply picking up the effect of the omitted cooking time and peak-exposure variables. The implication of these Kenyan studies is that, based upon average exposures, the policy interventions suggested by the World Bank team in Bangladesh (Dasgupta *et al.*) – to increase roof and wall ventilation in houses – may not be efficacious because these recommendations are uninformed by the importance of the micro-environment and who in the household "stirs the pot." Houses ventilation may thus not be sub-optimal.

Even with good measures of individual exposure in a micro-environment there is a potentially serious problem with the Kenyan study and most other studies in the exposure response literature - the analyses assume that exposure to smoke is exogenous. In general, the literature on IAP exposure also appears to assume that individuals in settings in which there are no alternatives to biomass fuels are unaware of the health consequences of their use, so the differential exposure to smoke among individuals is essentially random and observed behavior is sub-optimal even given constraints. However, if there is heterogeneity in health and such heterogeneity influences the division of tasks within the household, whether due to optimizing behavior or other reasons, causal inferences cannot be drawn from studies that do not pay sufficient attention to the nature of allocative decisions in the household. Indeed, Bruce *et al.* (2000) provides a recent survey of a large number of papers estimating the health effects of indoor air pollution in developing countries and concludes that the observational nature of most studies and the inadequate control for heterogeneity results in biased estimates of risk.

In this paper we use new survey data on the health and time allocation of individuals in rural households in Bangladesh and India to investigate how and to what extent the division of household responsibilities, household structure, nutritional intake, the physical structure of the house, fuel choice and stove types affect both child and adult health, given household optimizing behavior. IAP levels in Bangladesh are very high. Dasgupta *et al.* (2004a) find that concentrations of 300 $\mu g/m^3$ or higher are common in Bangladeshi households. In comparison, the California Air Resources Board has set an indoor air quality standard of 50 $\mu g/m^3$.[1] There is, moreover, great variation within the day, with the peak reading for the "dirtiest" household of 4,864 $\mu g/m^3$, and, as in many studies of IAP, Dasgupta *et al.* find that IAP levels are highest in kitchens and at cooking times, and that the variation in exposure was greater within houses over time than between houses. The decision of who cooks within a household and for how long therefore is critical in a setting in which fuel choice is limited to biomass.

The data set we use from Bangladesh, the 2002-2003 Nutrition Survey, provides detailed information on the time allocation and nutrient intake of all family members across a 24-hour period, on health symptoms, location of kitchen facilities, and features of house construction. In a setting where alternative energy sources are not available, we show how these data can be used to assess to what extent, if at all, exposure to cooking-related smoke causally affects health when there is health heterogeneity, to assess the efficacy of improved ventilation associated with construction materials, and to identify to what extent household decisions about who cooks reflect an awareness of the health consequences of IAP. The data set from India, the 1999 Rural Economic and Demographic Survey (REDS 1999), has similar information as in the Bangladesh

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[1]A very recent study (and accompanying editorial) published in the *New England Journal of Medicine* (Gauderman *et al.,* 2004) finds striking effects of air pollution on lung development and function measured annually for eight years among California children 10-18 years of age. The most polluted community among the 12 study communities had a seven-year mean PM_{10} of approximately 65 $\mu g/m^3$ and the remainder were between 15 and 42 $\mu g/m^3$, compared to the 300 $\mu g/m^3$ common in Bangladesh. The estimated proportion of children with low forced expiratory volume (FEV_1) was predicted to be 4.9 times higher at the highest level of community particulate exposure ($PM_{2.5}$) than at the lowest level. Such striking effects when concentrations are far lower than in Bangladesh suggests the potential health effects of reducing IAP in Bangladesh. In this study too, exposure (associated with location) is assumed to be random.

survey except that across India households use different cooking fuels and stove types, which are documented in the data. However, there is only information on health symptoms for children.

In section II of the paper, we set out a simple model of household time allocation incorporating health heterogeneity to highlight the determinants of who cooks when households are fully informed about, and attempt to minimize, the "disease burden" of IAP but cannot substitute away from biomass fuels. The model delivers the results that there will be specialization in cooking, that less healthy individuals will cook, and that child care responsibilities will affect individual cooking assignments in the household, reflecting both the burden of child care and the consequences for children's exposure to IAP. Such optimizing behavior and full information lead to upward-biased estimates of the ill-health effects of exposure to IAP when exposure is measured without error. Section III contains a description of the data and descriptive statistics on the allocation of time of household members, and respiratory and intestinal symptoms by age and gender. These show a high correlation between respiratory symptoms and cooking tasks, which are almost exclusively assigned to women, that is not observed for intestinal symptoms.

In section IV we set out our econometric strategies to identify the own health effects of exposure to IAP associated with cooking time, which exploit social hierarchies within the household, and report the estimates of how cooking time and thus stove proximity affect the incidence of respiratory and intestinal symptoms. The estimates indicate that cooking time, unlike calorie consumption, affects respiratory but not intestinal symptoms, that these effects are not mitigated by more permeable house construction or kitchen location, and that estimates that do not take into account both measurement error and heterogeneity result in a significant downward bias of IAP effects on ill health. In section V we examine intergenerational exposure effects, estimating how the mother's cooking time affects her child's health, again taking into account individual health heterogeneity. We find that the effects on children are age-dependent, with respiratory problems of children younger than five more severely affected than respiratory problems for children 5-9 for a given increase in maternal cooking time. We apply the same methodology to estimate exposure effects by age on children using the Indian household data, but include estimates of how fuel choice and stove type mediate exposure effects. In section VI we examine the determinants of cooking time using both the Indian and Bangladesh data sets, in particular exploiting panel data on direct measurements of person-specific health endowments in the Bangladesh data.. The estimates are consistent with both the social hierarchy of status among women in Bangladesh and India and the full-information optimizing model in which households minimize “disease burden” - mothers endowed with less health spend more time cooking, mothers who have child care responsibilities spend more time cooking, but among such mothers with the youngest infants (below five) cooking time is reduced.

II. Theory

We set out a simple heuristic model to show how households seeking to minimize the burden of an unhealthy but necessary activity will allocate the unhealthy task among its members. Consider a separable household utility function of the form

(1) $$U = U_m(H_m, X_m) + U_f(H_f, X_f)$$

where $H_m = (h_{m1} h_{m2}, \ldots, h_{mJ})$ is the set of health statuses of the J males in the household, $H_f = (h_{f1}, h_{f2}, \ldots, h_{fK})$ is the set of health statuses of the K females in the household, and $X_m = (x_{m1} x_{m2}, \ldots, x_{mJ})$ and $X_f = (x_{f1}, x_{f2}, \ldots, x_{fK})$ are sets containing the allocations of composite consumption goods. For simplicity, we abstract from leisure and assume that a single unit of time is allocated between a productive activity that is deleterious to health (“cooking”) (t_c) and productive employment (t_a, “agriculture”) that is not. Only women devote time to the cooking activity, and so we will only focus on the household’s allocation of women’s time.[2] To simplify exposition, assume that K=2, and that the total quantity of cooking time t_c that women in the household must provide is fixed. Consequently, time spent cooking must be allocated such that $t_{c1} + t_{c2} = t_c$. Health for women is produced with technology

(2) $$h_{fi} = h_f(t_{ci}, x_{fi}) + \mu_{fi}, i = 1, K$$

[2]We do not seek to explain the gender division of labor. In the spirit of the model, however, if on average men are more productive in agriculture than are women, then we would observe more cooking by women than by men on average in health-burden minimizing households. If all women have children, this always leads to reduced productivity and time spent in agricultural tasks (see below), and if there are high returns to specialization over time, one can obtain the result that almost no men would cook.

(3) $$\frac{\partial h_f}{\partial t_c} < 0, \frac{\partial h_f}{\partial x_f} > 0$$

where μ_{fi} is the exogenous component of health (health endowment).

The productivity (earnings) of time spent in agriculture is sensitive to health

(4) $$w_{fi} = w_f(h_{fi}), i = 1,2$$

(5) $$\frac{\partial w_f}{\partial h_f} > 0$$

but the productivity of time spent cooking, t_{ci}, is the same for all values of h_{fi}. Households maximize the utility function (1) subject to (2), (4), the time constraints, and the budget constraint

(6) $$v + \sum w_{fi} t_{ai} - p \sum x_{fi} = 0$$

where v is the sum of non-earnings income and male earnings net of their consumption ($\sum w_{mi} t_{ai}$ - $p \sum x_{mi}$), and p is the price of consumption good x.

Consider a model nested in this utility maximization problem, in which women's contribution to household income, the left-hand side of (6), is maximized subject to the time constraints. Because health only affects income through agricultural work, then when all women are identical ($\mu_{f1}=\mu_{f2}$) and $t_c \leq 1$ (household cooking time is less than the time available to any one women), specialization may be optimal - one woman will do all of the cooking and the other woman will specialize in agriculture if cooking time requirements are sufficiently high.[3] However if one woman is innately less healthy than another ($\mu_{f1}<\mu_{f2}$), then that woman will always spend more time in the kitchen. The rationale is clear – any time spent in cooking by a woman reduces her health and productivity in agriculture without affecting her productivity in

[3]In the case in which, for example, the health production function is quadratic in t_c and the wage function is linear in health, specialization will occur if $t_c > 2/3$. If $1 < t_c \leq 2$, one woman would only cook and the other woman would split her time between cooking and working in agriculture.

cooking.

In the utility-maximization case, a compensatory household may not exhibit complete specialization by task, reflecting the disutility of health reductions caused by cooking. Nonetheless, even with identical women ($\mu_{f1}=\mu_{f2}$), the differential effects of health on the productivity of time by task, will, in general, result in one woman spending more time cooking than the other, meaning an unequal sharing of the health burden. And if $\mu_{f1}<\mu_{f2}$, the less healthy woman will be the one to devote more time to cooking. Thus, the observed association between time exposed to an unhealthy environment and ill-health will be an upward-biased measure of the effect of exogenously increasing exposure.

The productivity function (4) can be generalized to

(7) $$w_{fi} = w_f(h_{fi}, \lambda_{fi}), i = 1,2$$

(8) $$\frac{\partial w_f}{\partial \lambda_f} < 0$$

where λ_{fi} is any characteristic of a woman that affects productivity in agriculture but does not alter utility directly. As before, the productivity of time spent cooking is assumed to be unaffected by both h_{fi} and λ_{fi}. One important example of λ_{fi} is the need to care for one's own infant or young child, which may diminish the productivity of a woman's time in agriculture but have little effect on cooking efficiency.[4] For example, it may be much harder for a woman to tend to her child while weeding or transplanting rice compared with cooking rice. If a woman who cares for an infant or young child ($\lambda_{fi}>0$) has lower productivity in agriculture she, all else being the same, will tend to spend more time cooking than another woman in the household without a young child ($\lambda_{fi}=0$).[5] If an important reason that cooking and child care are joint products is the

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[4]Any cognitive or physical ability, such as schooling or ability, that has a return in the labor market but not in cooking, and which may not be observed in the data, are components of λ_{fi}

[5]In a household with two women having equal values of λ_{fi}, the relative allocation of time spent cooking will still depend on the health endowment μ_f. If the productivities λ_{fi} are positively correlated with health endowments μ_{fi} (high-ability women tend to have more exogenous health), and if the efficiencies of specialization influence a household's allocation of women to tasks,

proximity of mother and child, as for very young infants, then there are potential exposure effects for the child when the mother is exposed to the unhealthy environment. In a more elaborate model in which the health of children are also a component of household utility, given that the youngest children do not contribute to household income or production, mothers with very young children may temporarily spend less time in the unhealthy activity.

In the South Asian context, relative productivities (λ_{fi}) and health endowments (μ_{fi}) may not be the only factors that allocate women to tasks, but also the identity of women in terms of their relationships to the household head. In particular, Cain *et al.* (1979), in describing decision-making in Bangladeshi households, report that mothers-in-law dominate daughters-in-law, mothers dominate daughters, and elder brothers' wives dominate younger brothers' wives. A young wife submissively follows the lead of her husband's mother, and is rarely involved in decision-making (Chowdhury 1995). The autonomy of women from the oversight of their mothers-in-law increases with the birth of her children and her age. The death of the father-in-law undermines the authority of the mother-in-law but does not destroy it. Young daughters-in-law cannot leave the *bari* (family compound) without permission, and adherence to *purdah* (seclusion of women) is more strict for a young wife. After several years and births, a daughter-in-law gains some autonomy of action and movement relative to her mother-in-law and other women in the household, including other daughters-in-law. When she has her own daughter-in-law within the household, her freedom is enhanced and she is ordinarily free to leave the *bari*, leaving the completion, but not the management, of household chores, including cooking, to her daughter-in-law.

Fafchamps and Quisumbing (2001) suggest that such a system of changing social status among the women in a household may be a socially acceptable mechanism that avoids costly bargaining and friction by simplifying the time allocation process in ways that preserve many, but not all, of the benefits of specialization and comparative advantage. They suggest that if social

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then the correlation between unobserved health heterogeneity and cooking time will be larger. If the need to care for children is the source of differential efficiencies, and if high health endowment women have more births, then efficiency λ_{fi} may be negatively correlated with health endowments μ_{fi}.

norms were the only determinant of time allocation within the household, the efficiency cost would potentially be very large. The existence of such norms, however, provides a source of variation in household tasks that is independent of individual productivity and health that we exploit in the econometric results reported below. We also show that within-household status affects time allocation strongly, but only has weak effects on the intra-household allocation of another important household resource - food consumption.

III. Data

The data for our analysis comes from two surveys: the 2000-2003 Nutrition Survey of Bangladesh and the 1999 Rural and Demographic Survey (REDS). The Bangladesh survey sample has two components. It includes (1) a random sample of all households in 14 villages that was carried out in 2000, and (2) a panel survey, consisting of the households of all surviving individuals included in the 1981-82 Nutrition Survey of Bangladesh (Ahmed and Hassan, 1983) (originally sampled from the same 14 villages) regardless of their residence during the interval 2000-2003, some of whom were also included in the 14 village random sample frame of year 2000. Taken together, this data set provides multi-level (individual, household and village) survey information on health status, activities, nutritional intake, and resources for over 4000 men and women. A key feature of the panel component of the survey is that, by including individuals who departed from the original 14 villages chosen in the 1981-82 survey, it is characterized by very low household and individual attrition rates despite the approximately 20-year interval between rounds.

The questionnaires in the Bangladesh survey elicited information on (i) activities, including those for pay and not for pay, as well as the earnings from paid activities, (ii) home dimensions and construction materials, and (iii) household expenditures. Information on housing includes the location of the kitchen (outside or not) as well as roof and wall material. Because roof and wall permeability mediate the dispersion of point-source smoke and were identified as important objects of policy in the research of the World Bank team, they are important variables for our analysis of the effects of IAP in Bangladesh.

The time-activity information is a detailed and exhaustive list of all market and non-market activities, such as pounding grain, cooking, cleaning, and time spent with children, in a

24-hour period. Activities were coded into more than 150 categories, of which seven were "household chores" separate from child care. A key feature of this module is that activities are anchored around the five prayer times observed during the day, salient features in the lives of the Muslim respondents. The accuracy of the amounts and timing of activities is thus aided by these multiple set points that are endemic to the study population.

The time-allocation information is important because, as shown in prior studies, it is proximity to the point source of pollution - the stove - that has important effects on respiratory health. With detailed information on time spent in the kitchen when cooking for all household members combined with information on wall and roof construction and/or point-source pollution, we can, as discussed below, identify the effects of IAP on children's and adult health and test for the influence of housing characteristics.

The data suggest that respiratory problems are both prevalent and correlated with time spent cooking in the Bangladesh population. The Bangladesh survey contained a checklist of 23 health symptoms for all household members. These are provided by each household respondent over age 10, and for children less than or equal to 10 by the relevant mother. Of the 23 symptoms, three symptoms are respiratory-related (coughs, difficulty breathing, with or without fever). Figure 1 provides the proportion of individuals in the Bangladesh sample with one or more respiratory symptom by age and gender. As can be seen, over 37% of boys and 32% of girls younger than five exhibited some respiratory symptoms. This difference is statistically significant (N=900). The incidence of respiratory problems evidently declines with age and starting at age 15 or so, the gender difference reverses as women exhibit more respiratory symptoms than do men, the difference being statistically significant in the age group 25-50 (N=2488). In that age group, over 17% of women report respiratory problems, compared with12% of men.

The time allocation data were collected from household members according to the same rules as for health symptoms. Figure 2 provides the average minutes per day spent in kitchen chores (cooking and food preparation) by Bangladesh women for the same age groups as reported in Figure 1 for respiratory symptoms. The data show that the youngest children, unsurprisingly, spend little time in this activity, but that women starting at age 10 do almost all of the cooking and spend on average considerable time in this activity, with women aged 25 through 50 spending almost 4.5 hours per day in the kitchen. The gender differences and age-gradient in cooking time allocation (Figure 2) corresponds to respiratory symptoms (Figure 1) for the women above age 15 in a way consistent with the hypothesis that cooking time and thus exposure to smoke adversely affects health - the incidence of respiratory ailments among women grows as their average time spent cooking increases, and the gender gap in respiratory symptoms also grows with the gender gap in cooking time. That children less than five have a higher incidence of respiratory problems than do their somewhat older siblings is consistent with young children staying close to their mothers. Their exposure to smoke is thus similar to that of the women over age 15, but they are evidently more vulnerable to smoke exposure.

Table 1 provides summary statistics and definitions of all of the variables used in the analysis using the Bangladesh data.

The 1999 REDS is a probability sample of 7,474 households residing in 250 villages in 17 states of India. The information collected is similar to that in the Bangladesh survey. However, because across India there is variation in fuel used and stove types, which are recorded in the data, it is possible to identify the health effects of both cooking fuel and stove type. Figure 1a reports the distribution of stove types in the sample. As can be seen, over 75% of the sample households cook with a stove that uses biomass, with only a small subset of those using a stove that is designed to reduce smoke. The main alternatives to biomass as fuel - firewood, dung, charcoal, and soft coke - are kerosene and gas, as seen in Figure 2a, which reports annual expenditures on fuel (including imputed values of home produced or collected fuel). On average, these clean cooking fuels and gas are only 33% of average total expenditures on fuel used for cooking.

The REDS also provides time allocation data for over 10,000 women covering three twenty-four hour periods based on half-hour intervals. However, cooking time, washing and child care time are lumped together so that it is not possible to well measure using this information exposure to smoke. There is also a principal activity question, which identifies those women whose principal activity is household work. A second shortcoming of the data is that there is only information on health symptoms for children in the household, although it is as detailed as in the Bangladesh survey. Thus, the data permit an investigation of how exposure to smoke via proximity to a mother who herself is proximate to a pollution source affects child health as in the Bangladesh data. However, it is also possible to explore how the health effects of proximity to the stove are mediated by fuel used, by type of stove, and by stove venting.

As seen in Figure 3a, there is a high percentage of children aged 2-9 reported as having respiratory problems in the year prior to the survey in the sampled Indian households. Consistent with the Bangladesh data and with the closer proximity of the youngest children to mothers, Indian children 2-4 are more likely to have cough symptoms reported by mothers than are children aged 5-9. Such symptoms are also more prevalent among households using biomass compared with households using clean fuels or smokeless stoves - among children 2-4 years of age, children in homes without smokeless stoves/fuel are 37% more likely to have respiratory problems compared with similarly-aged children in homes with smokeless cooking. These statistics are only suggestive, however, as the health effects of maternal proximity depend on whether or not the mother is assigned cooking chores, which is a household choice, as is fuel and stove type.

IV. Does cooking time cause respiratory illness symptoms among adults?

A. Estimation strategy. It is possible to interpret the relationships between Figures 1 and 2 as merely indicating that poor households, who have poor health, have a greater number of younger children and women who spend more time cooking. Similarly, households with traditional stoves in India may be poorer and thus of general ill-health. To quantify more precisely the relationship between exposure to smoke associated with time spent in the kitchen, and take into account health heterogeneity, we exploit the data more fully. The equation we estimate is given by

$$\textbf{(9)} \qquad h_{ij} = \alpha_t t_{ij} + \boldsymbol{\alpha}_\mathbf{A}\mathbf{A}_\mathbf{ij} + \mathbf{Z}_j\boldsymbol{\alpha}_z + \mathbf{X}_j\boldsymbol{\alpha}_X + \mu_{hj} + \mu_{hij} + e_{hij},$$

where h_{ij} is the incidence of any respiratory symptom for person i in household j; t_{ij} is the time spent cooking; A_{ij} is a set of person-specific attributes (age, sex, education); $\mathbf{Z}_j$ is a vector of household-level smoke-related factors that reflect ventilation (permeability of walls and roof, and whether cooking is carried out outdoors); $\mathbf{X}_j$ is a vector of other household-level characteristics that may affect health, such as income; and α_t, $\boldsymbol{\alpha}_A$, $\boldsymbol{\alpha}_z$ and $\boldsymbol{\alpha}_X$ are the corresponding vectors of coefficients. Equation (9) also contains terms capturing health heterogeneity, divided into a household health component μ_{hj}, an individual-specific health component μ_{hij}, and an iid error term e_{hij}.

The coefficient of interest is α_t, which expresses the relationship between an individual's time spent proximate to a stove and their respiratory health. The problem for estimation is that cooking time may be correlated with unmeasured household and individual-specific health variables. To eliminate household unobservables, we use a household fixed-effects procedure, which differences across women in the same household

(10) $$\Delta^j h_{ij} = \alpha_t \Delta^j t_{ij} + \boldsymbol{\alpha_A \Delta^j A_{ij}} + \Delta^j \mu_{hij} + \Delta^j e_{hij} ,$$

where Δ^j is the across-person difference operator.

Estimates of α_t from (10) will not be consistent if (1) the within-household distribution of women's chores is related to the differences in individual health endowments, or (2) there is measurement error in the time exposed to smoke (t_{ij}) variable. The theoretical model presented in Section 2 suggests that there may be efficiency gains to the household in assigning less healthy women to cooking tasks, either because health differentially affects the productivity of time spent at tasks to which women are assigned, or because there is another non-health component of individual productivity that allocates women to tasks, and that component is correlated with health such that less healthy women spend more time cooking. In either case, α_t will be biased upward.

The measurement error issue arises if the time spent cooking varies from day-to-day and our measure, time-spent cooking in a particular 24-hour period, differs from average time spent cooking sampled over a greater period of time, or if there is recall error. If measurement error is of the classical variety -- uncorrelated with the determinants of health -- then the estimated parameter of interest α_t will tend to be biased downwards (attenuation bias). As is well-known, fixed-effects procedures exacerbate attenuation bias if there is measurement error in the regressor. The net effect of the two sources of bias is of opposite direction and unknown *a priori*.

To deal with the problems of heterogeneity bias and measurement error, we implement an instrumental variables procedure to estimate (10). We need variables that affect the allocation of cooking time across women in the same household but do not, given a women's time allocation, otherwise affect her health. As noted in section 2, households in rural Bangladesh contain sexually segregated spheres of influence in which gender-specific hierarchies, based in large part on relationship to the head of household, operate to allocate women to tasks based both on the gains from specialization and on rank in the household hierarchy. Differences across women in their relationships to the household head are unlikely to directly affect differences in respiratory health or to be correlated with individual health endowments or productivity net of age. Thus, the identity of a household member as a daughter-in-law or the wife of the head and their interactions are used as instruments to identify the effect of time spent cooking on health. Note that because (10) nets out the household fixed effect, the estimation procedure is robust to household structure being correlated with the household-level health unobservables (endogenous household structure).

B. Estimates of direct exposure effects. Table 2 provides estimates of the effects of cooking time on the incidence of respiratory symptoms for all adults in the sample of households, and for adult women only. Columns (1) and (4) present random-effects estimates that do not take into account either heterogeneity or measurement error. The estimate of α_t in column (1) suggests that respiratory symptoms are significantly related to cooking time but an individual's gender has no effect on such symptoms except through cooking time. This is the same finding reported in Ezzati and Kammen (2001) for their Kenyan sample using a similar estimation procedure as used to obtain the results in column (1). The size of the regression coefficient for cooking time α_t for the full sample is unaffected by dropping adult men from the sample in column (4). None of the ventilation measures that Dasgupta *et al.* suggest are related to smoke exposure – permeability of the roof, permeability of the walls, and the indoor/outdoor location of the kitchen – are statistically different from zero. Columns (2) and (4) present household fixed-effects estimates that control for all observed and unobserved sources of household-level heterogeneity, including the household health component μ_j, and all ventilation, kitchen location and size, and fuel use factors. These estimates do not address the possibility that the allocation to tasks within the household may be related to unobserved individual health endowments (μ_{hij}) through the efficient sorting of women to tasks, or the problem of measurement error in time allocation reports.

Instrumental variable estimates of the within-household and within-women models are presented in columns (3) and (6) of Table 2. The instruments are dummy variables indicating whether the person is a wife of the head or a daughter-in-law, the interaction of wife and daughter-in-law with the number of daughters-in-law, and the interaction of daughter-in-law with the presence of any wife of the head in the household. The set of hierarchical identifying variables are jointly statistically significant in explaining cooking time in the first stage equation for both the full sample of adults and the women only sample.[6] The FE-IV estimates of the effect of time spent cooking of the incidence of respiratory symptoms, α_t, more than triples for the full sample of adults, and nearly triples for sample of women as compared to the corresponding fixed effects estimates. A Hausman test rejects the null hypothesis that $(\alpha_1^{FE\text{-}IV} - \alpha_1^{FE})=0$ for the full sample at the 2 percent level (t=2.27) and for the women sample at the 8 percent level of significance (t=1.75). In both cases, the estimated effect of time spent cooking on respiratory illness is large and statistically significant. The point estimates indicate that a four hour per day increase in the time spent cooking - notably the difference between the average hours spent by women and by men - is associated with a 10.8 percentage point increase in the probability of reporting a respiratory symptom. In elasticity terms, a doubling of cooking time increases the probability of respiratory problems by 36 percent.

The model of a household with health heterogeneity described in Section 2 would suggest that the FE estimates would overestimate the true effect of cooking time if less healthy women were assigned to cooking. The underestimation of α_t in the fixed-effect models of columns (2) and (4) results suggests that measurement error is the predominant source of bias, or that it is women with better respiratory health who are sorted into cooking. We present direct evidence on the sorting of women by health status below.

C. Diagnostics. Before proceeding to assess how direct exposure to the pollution source interacts with the physical dimensions of the house, we assess our estimation strategy to identify the effects of exposure. As noted, our procedure assumes, consistent with the anthropological literature, that the hierarchy of women by marital status and relationship to the head affects time allocation and that this status in the household has no other effects on health. One means of

[6]The test-statistics are F(5, 2647)=171.5 and F(5, 828)=29.6. The sign patterns of the women's status variable generally conform to those indicated in the anthropological literature, and are discussed below.

testing this directly is to carry out over-identifications tests, and we find that the hypothesis that the fixed-effect, second stage residual is uncorrelated with the set of hierarchy instruments cannot be rejected at standard levels of significance. The F-statistics (significance levels) are 1.07 (0.37) and 0.99 (0.42) for the full sample of adults and for adult women, respectively.

There are two problems with the over-identification tests. First, it is not obvious that the tests have power. The second is that cooking time may be highly correlated with some other variable that affects health, such as nutritional intake. To assess whether the relationship between cooking time and respiratory systems is spurious and whether the over-identification test has power we first estimate using the same specification the effect of cooking time on health symptoms that are not implicated in the literature as being directly affect by exposure to particulates in the air. If in our data it is found that cooking time "causes" non-respiratory symptoms not known to be affected by exposure to smoke, that would be an indication of a spurious relationship between cooking time and health that might also affect the FE-IV estimates in Table 2. Consider a health outcome, d_{ij}, such as intestinal symptoms, for which individual cooking time is unlikely to be related on *a priori* grounds, and write the analogous form of equation (9):

(11) $d_{ij} = \beta_t t_{ij} + \boldsymbol{\beta}_\mathbf{A} \mathbf{A}_{\mathbf{ij}} + \mathbf{Z}_j \boldsymbol{\beta}_z + \mathbf{X}_j \boldsymbol{\beta}_X + \mu_{dj} + \mu_{dij} + e_{dij},$

where all the independent variables are defined as they were for equation (9), but the household- and individual-level health endowments contributing to health outcome d_{ij} are μ_{dj} and μ_{dij}, respectively, rather than μ_{hi} and μ_{hij}. The μ_{dij} and μ_{hij} individual health endowments may have common components so that $E(\mu_{dij}\ \mu_{hij}) \neq 0$, and similarly for household health endowments μ_{di} and μ_{hi}. If our fixed-effects-instrumental-variable procedure did not correct for the purposive allocation of less healthy women to time cooking, we should expect to see $\beta_t > 0$.

Table 3 presents FE-IV estimates of the determinants of the effects of cooking time on the incidence of intestinal symptoms, using the same set of identifying instruments as were used to estimate the determinants of respiratory symptoms, for the adult and adult female samples. In both samples, the estimated effects of cooking time are small and statistically insignificant. Thus, we find that time spent cooking affects respiratory symptoms, but there is no evidence that it affects intestinal symptoms in the same sample using the same estimation procedure.

The finding of β_t=0 is consistent with, but not sufficient to establish, the validity of our FE-IV procedure.[7] Moreover, the overidentification F-statistic for the intestinal symptoms specification, 1.81, is significant at the 10% level, suggesting that there may be omitted inputs affecting intestinal symptoms that are correlated with the instruments. We thus also add to the respiratory and intestinal symptom equations an additional endogenous input - the individual's calorie consumption, based on the 24-hour observed (and weighed) consumption intakes of family members that were collected as part of the survey. Food consumption and nutrition should affect the probability of stomach-related ailments; their effects on respiratory symptoms are not known. We also carry out the over-identification tests with this additional input to health included for both dependent variables.

The allocation of calories in the household is also a choice, and appears to be significantly, but less strongly related to the hierarchy variables. Table 4 reports for the full sample of adults the first stage equations for both cooking time (used in obtaining the estimates in Tables 2 and 3) and individual calorie consumption with and without the female status variables. As can be seen, the set of status variables are statistically significant determinants of both household resources, but the addition of this set of variables increases the explanatory power of the cooking time regression by almost 13%, while hardly adding to the explanatory power of the calorie equation. These findings are consistent with the South Asian anthropological literature.

Table 5 reports the estimates of the effects of cooking time on respiratory symptoms, on body weight, and on the intestinal symptoms in specifications that include calorie consumption. The point estimate for cooking time in the respiratory symptom equation is essentially unaffected by the inclusion of calorie consumption and remains statistically significant. The cooking time

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[7]This comparison of α_t and β_t is akin to a differences-in-the-difference estimator in which one of the differences is between women in the household, and the other is between diseases, where the treatment (cooking time) is presumed to not alter the intestinal symptoms outcome, and so represents the control. For this to be a valid implementation of differences-in-the-difference, it is necessary that chore assignments are based on a common general health and not on specific health symptoms, such as coughing or intestinal disorders. However, it is still possible that women of the same general health but who exhibit respiratory problems (as opposed to other health problems) are assigned non-kitchen chores, which would bias α_t downward.

effect is thus not just picking up a general allocation of resources. Indeed, the effect of calorie consumption on the probability of respiratory problems is small and not statistically significant. This latter result is not due to lack of variation in calorie consumption - the estimate of the effect of calorie consumption on body weight, given the allocation of time, (column 2) is significant and positive, as it is in the intestinal symptoms equation (column 3).[8] In the latter equation, cooking time is still, however, not significantly related to intestinal symptoms, net of food intake, consistent with biological models. Moreover, the intestinal symptom specification now passes the overidentifying test (F(5,2502)=0.47), which evidently has power.

D. Do ventilation and kitchen location matter? Having assessed the robustness of the instrumental-variables estimation strategy for identifying smoke exposure effects on respiratory ailments using cooking time, we look at the interaction between exposure and ventilation. The work of the World Bank team in Dasgupta *et al.* in Bangladesh suggest that ventilation is a major determinant of particulate density. They find that kitchen location and the permeability of the roof and walls are the most important determinant of particulate density at various points distant from the cooking fire as measured with particulate concentration monitors. The problem is that their data provide no measures of health or of the actual inhalation of airborne particles. Without knowing where household members are situated in space at the time the cooking fire is ablaze, and how the smoke inhaled affects respiratory health, the mapping from particulate concentration to individual health is tenuous. In Table 2, columns (1) and (4), we found no evidence that either the permeability of roof and walls or the location of the kitchen inside or outside of the residential dwelling influence the incidence of respiratory symptoms in a random effects specification. Those estimates make no attempt to control for household-level heterogeneity that may bias inference, however.

We now directly test whether the permeability of roof and walls and the location of the kitchen inside or outside of the residential dwelling reduce the deleterious effect of time spent

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[8]Interestingly, body weight, given calorie consumption, rises with increased cooking time, possibly reflecting the relatively sedentary nature of this activity compared with agricultural work.

cooking on respiratory symptoms by interacting the housing material and kitchen location variables with the exposure measure, using our FE-IV method. The results, reported in Table 6, provide no support for the hypothesis that ventilation matters for either the all-adult or the only-women samples. These results are in accord of those of Ezzatti and colleagues, who found that only those persons very close to the fire, within 0.5 meters, are importantly affected by the smoke of kitchen fires. Thus, while the World Bank may stress that simply improving roof and wall ventilation in the homes of the poor is an inexpensive and efficacious policy intervention that unenlightened Bangladeshi's are unaware of, such a conclusion is not supported by our estimates.

V. Intergenerational effects of indoor air pollution

Mothers with infants and young children are likely to devote significant amounts of time to their care and keep them close at hand. If children are kept physically close to their mothers as the mothers cook, they may also be at risk for the respiratory symptoms caused by their proximity to the cooking fire. We can use a similar approach used to examine the effects of cooking on adults to investigate the presence of intergenerational health externalities associated with the combination of child care and cooking responsibilities assigned to women using both the Bangladesh and Indian data. For each child in the household, we know the time allocation (Bangladesh) or principal work activity (India) of his or her mother. For children between the ages of two and nine years[9], we estimate the following equation

(12) $$h_{ijk} = \gamma_0 + \boldsymbol{\gamma_A A_{ijk}} + \gamma_t t_{ij} + \gamma_D D_{ijk} t_{ij} + \mathbf{Z}_j \boldsymbol{\gamma}_z + \mathbf{X}_j \boldsymbol{\gamma}_X + \mu_{hj} + \mu_{hij} + e_{hijk},$$

where h_{ijk} is reported respiratory symptom of a child k (age 2-9 years) born to mother i in family j, A_{ijk} is the age, age squared and gender of the child, D_{ijk} is a dummy variable if the child's age is 2 to 4 years of age, and t_{ij} is the time allocated to cooking by the child's mother. The interaction $D_{ijk}t_{ij}$ in equation (12) permits the effects of the mother's exposure to smoke while cooking on the child's respiratory health to differ by child age. Older children can be farther away from their mothers than younger children and yet still be safely cared for, yet are still too young to engage in

[9] Infants 0 and 1 years of age are excluded in the analysis because, as suggested by regression estimates discussed below, mothers of children this young do significantly less cooking, perhaps in response to knowledge about the deleterious effects of cooking smoke on infant health.

cooking over a fire alone. The relationship between the mother's cooking time and a young child's health thus will be due to either (a) exposure to smoke associated with being proximate to the mother or (b) a correlation between a mother's endowed healthiness, the child's inherent healthiness and the mother's time allocation. Household fixed effects estimation used in estimating previous models only differences out household-specific heterogeneity μ_{hi}. However, the presence of multiple children for mothers in the sample permit us to difference across children of the same mother, thereby eliminating all mother-specific heterogeneity μ_{hij}. In doing so, we can only identify the coefficient γ_D, which indicates whether and how maternal exposure to smoke and child health varies by child age.

Table 7 reports the estimates for the Bangladesh sample. The household fixed effects estimate of the effect of a mother's time cooking on child respiratory symptoms in column (1) of Table 7 is positive and marginally significant at the 5 percent level (t=1.93). We would expect that the effect of a mother's cooking on child symptoms would be greater for younger children, as they are likely to be spend more time closer to their mother than do older children. The estimates of column (2) bear out this hypothesis. The mother fixed-effects estimates in column (3) correct for any correlation between the mother's endowed health, the child's inherent health, and the mother's time allocation, and yield an unbiased estimate of the differential effect of mother's cooking time on younger (2-4 years of age) as compared to older (5-9 years of age) children. This effect is positive and significantly different from zero (t=2.19). This result is additional evidence that (i) it is direct proximity to the point source of indoor air pollution, the cooking fire, that is the cause control of respiratory symptoms, and (ii) indoor air pollution arising from cooking has deleterious effects on the respiratory health of anyone near the point source, in particular, the youngest children of those who cook. Note that the evidence of measurement error presented earlier suggests that estimates of column (3) are lower-bound estimates of the true effect of cooking time on child health.

In the last three columns of Table 7 we present estimates of the effect of mother's time cooking on the report of intestinal symptoms of children. As in the case of the mother's own intestinal symptoms, we find no evidence that the mother's cooking time affects these symptoms for her children.

Table 7a reports estimates from the same specification for the children in the Indian sample. In this case, we can also examine whether the mother's cooking affects her youngest child's health more adversely and whether that effect is mitigated by fuel use and direct venting in the form of a chimney or general ventilation, in the form of a window in the kitchen. Columns one and two in Table 7a report the within-household (conditional logit) estimates of the effects on the probability of the child having respiratory symptoms in the past year of having a mother who specializes in home activities. Unlike in the Bangladesh sample in which all households use biomass, as seen in column one there does not appear to be an effect on average for the youngest children of maternal exposure to cooking in India. However, in households using biomass for cooking and a traditional stove (column 2), children 2-4 are significantly more likely to have respiratory symptoms compared with children in smokeless homes. And this effect persists when the within-mother estimator is used (column three).

The estimates in columns four and five are informative with respect to the issue of whether direct or indirect exposure to smoke is more adverse, and thus whether general ventilation is effective. The estimates from column four suggest that traditional stoves with chimneys have reduced effects on respiratory symptoms for children 2-4 compared with households without chimneys but using biomass fuel. However, given stove type and direct venting, having a kitchen window is ineffective in reducing respiratory symptoms in households using biomass. Consistent with the estimates from the Bangladesh survey and with the biomedical exposure literature, general house ventilation does not appear to be an effective alternative to stove design and fuel policy in reducing respiratory illness.

Finally, Table 7b reports estimates from the identical specifications and estimation procedures used in Table 7a for the Indian households, except that the dependent variable is the incidence of intestinal symptoms. As in the Bangladesh data, a mother's cooking with biomass and venting does not appear to be related to the probability of intestinal symptoms among her youngest children, unlike for respiratory illness.

VI. Who Cooks? The Determinants of Cooking Time

The estimates of cooking time effects on respiratory illness symptoms indicate that greater exposure to point-source pollutants associated with cooking adversely affects the health of the person who cooks, and her young children, especially the youngest. The simple optimizing model which assumes that individuals understand the health consequences of their activities, but have no scope for fuel substitution or stove modifications, as in Bangladesh, will allocate unhealthy tasks to individuals who are for other reasons less capable of contributing to earnings, due to endowments or alternative responsibilities such as child-rearing.

Table 8 presents household random effects and fixed effects estimates of the determinants of cooking time among the Bangladesh households. These estimates establish three things. First, the identifying instruments based on women's relative status in the household – wife of head, daughter-in-law of head, and the interaction of wife with number of daughters-in-law – that were used in the first stage again have power in predicting time spent cooking. Both wives and daughters-in-law spend more time cooking than other women in the household, who are primarily daughters of the head. Second, mothers with children 5-9 years of age cook more, and mothers with children 0-4 cook less. Children in the youngest age group are likely to stay very close to their mothers, and if their mothers cook, these children will be exposed to particulate concentrations similar to that of their mothers. As Tables 7 and 7a suggest, respiratory symptoms of the youngest children are more sensitive to the cooking time of mothers. Older children (aged 5 - 9 years of age) do not have to be as spatially close to their mothers, but the need to watch over them may make women less efficient (in the sense of Section 2) in alternative chores if those chores keep them from watching their children or put children at some risk. Third, Table 8 reveals that years of schooling and cooking times are negatively related. This is the prediction of the efficient specialization model of Section 2 if, as seems likely, the returns to education in cooking are less than in other tasks. Ten years of schooling reduces a woman's time spent cooking by nearly 75 minutes per day compared to an unschooled woman, using the FE estimates with the women-only sample.

Table 8a reports conditional logit (within-household) estimates of the determinants of whom among the married women in rural Indian households specializes in household work. As in the Bangladesh households, the relationship of a woman to the household head matters for who is principally assigned household chores - daughters-in-law and sisters-in-law are more likely to be the "home-makers"compared with the wife of the head, with the wife of the oldest son evidently having priority over wives of younger sons. Unlike in the Bangladesh sample, however, mothers with children aged less than five are more likely to be engaged in home care. But, this relationship is attenuated in households in which cooking is less healthy - in households cooking with an unventilated biomass stove.

The results in Table 8 and 8a are consistent with a pattern of allocation that exposes women who are less productive or less able to fully participate in earnings activities (because of child-rearing responsibilities) to increased health risk, but reduces the particulate exposure of the most vulnerable children. This is consistent with a rational allocation of chores among households who care about child health and are at least somewhat aware of the adverse health effects of biomass fuels. Do we also observe less healthy women assigned cooking chores? As noted earlier, the sign of the bias resulting from not using instrumental variables does not help resolve this question as the instrumental variable method also corrects for measurement error in the time spent cooking variable, and these two sources of bias are of opposite sign.

To more directly address the issue of whether health endowments influence the allocation of time in accord with minimizing the household pollution burden, we exploit a unique feature of the Bangladesh data. A randomly-chosen portion of the 2000-2003 survey frame consists of all surviving individuals from the 1981-82 Nutrition Survey of Bangladesh. A key feature of this panel is that it was designed to track and interview all individuals included in the 1981-82 survey, including anyone who departed from the original 14 villages. The panel sample is thus characterized by very low household and individual attrition rates despite the approximate 20-year interval between rounds and the fact that 75 percent of young women in 1981-82 had left the sampled villages. In the 2002-2003 round, 97 percent of all surviving original sample subjects, and 96 percent of all surviving females were found and surveyed.

In Pitt *et al.* (1989), the 1981/82 household survey data were used to obtain a direct measure of the health endowment μ_{ij}. The health endowment was estimated from the residual of a weight-for-height production function including individual-level food consumption, water sources, and the energy intensities of activities as inputs. In that article, the health endowment was shown to significantly affect the intra-household allocation of food and tasks ranked by energy intensity. We can use these individual endowment measures, obtained from the 1981-82 data, to estimate the effects of health endowments on time spent cooking for the panel sub-sample to assess directly whether health endowments matter for the allocation of cooking time.

Is there reason to believe that these 1981-82 endowment measures predict health status in 2002-2003? Appendix Table A presents logit and conditional logit fixed effects estimates of the determinants of death by 2002 of all members of the 1981/82 households. For all estimation procedures - including those controlling for village effects and 1981-82 household effects, the 1982 health endowment is negatively and significantly related to the probability of death. That the health endowment predicts mortality is strong evidence that the estimated health endowment is a meaningful and time-persistent measure of health.

One problem in using the 1981-82 endowment measure to assess household decision rules in 2002-2003 is that the sample size is reduced, and thus the precision with which we can estimate parameters is less. To obtain within-household estimates, moreover, the effective sample size is further reduced because a household can only contribute to identification if it has at least two members in 2000-2003 who were in the 1981/82 survey for the "all adults" sample, and has at least two women from the 1981/82 survey living in the same household in the "all adult women" sample. Such households are obviously selective, but presumably all unmeasured differences between the panel households and others are subsumed in the household fixed effect.

Table 9 presents the household fixed-effect cooking time estimates including the 1981-82 health endowment for the 2002-2003 panel individuals. In column (1), the measured health endowment is negatively and significantly related to time spent cooking (t=-2.77) for the full adult sample – that is, in accord with the model of rational disease burden management, unhealthy women are called upon to do a disproportionate share of health-reducing cooking in the household. The endowment coefficient obtained from the sample including only adult women reported in column 2 has a point estimate twice as large, but the precision of this estimate is lessened by the decreased sample size. Attenuation bias resulting from measurement error in these 20-year old endowment measures implies, however, that these are lower bounds on the absolute values of the estimated endowment effects.

VII. Conclusion

In rural Bangladesh, households do not have a choice of cooking fuels and must use biomass, which prior studies suggest has adverse effects on health, particularly respiratory disease, due to indoor air pollution (IAP). In India, the large majority of households also use biomass as cooking fuel, many with unventilated stoves. Using surveys of rural households in Bangladesh and India with information on detailed person-specific time allocation, health symptoms and ventilation attributes of homes, we investigated the extent to which the division of household responsibilities, household structure, the roof and wall permeability and location of kitchen facilities, and stove and fuel types causally affect the health of women and children, taking into account optimizing behavior within households. We also explored whether households behave with respect to the allocation of the burden of the disease induced by IAP as if they are aware of its health consequences and seek to minimize its damage.

The results suggest that proximity to stoves adversely affects the respiratory health of women and the young children they supervise, that households appear to be aware of and attempt to mitigate the health effects of cooking with biomass fuels in their time allocation decisions, including effects on young children, such that women with lower endowed health have greater exposure to smoke and women with very young children have lesser exposure to pollutants. We also find, however, that due to measurement error, conventional estimates of the impact of smoke inhalation are underestimated substantially. These findings together imply that as smoke monitoring technology improves, estimates of the impact of indoor air particulates on health will increase in absolute value and may then overestimate adverse health effects given the activity assignment rules of households.

Finally, our results suggest that improving ventilation by increasing the permeability of roofs or walls has no significant effect on health, consistent with prior studies examining point-source pollutants and health data. Also consistent with this literature we find that stove chimneys, but not windows, mitigate the health consequences of cooking with biomass fuels. The fact that richer households in rural areas seek to make their houses less permeable thus does not reflect ignorance of the health impacts of IAP or an unwillingness to mitigate its effects.[10] Increasing

[10]In our data higher-income households have less permeable homes and spend no less time cooking on average, but exhibit no more respiratory disease symptoms than do poorer households.

opportunities for households to substitute biomass for cleaner fuels or to use cheap, pollution-reducing stoves appear to be more effective in improving the health of women and children in rural areas than programs that promote behavioral change, given existing choices.

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Figure 1: Proportion of Males and Females with Cough Symptoms, by Age Group

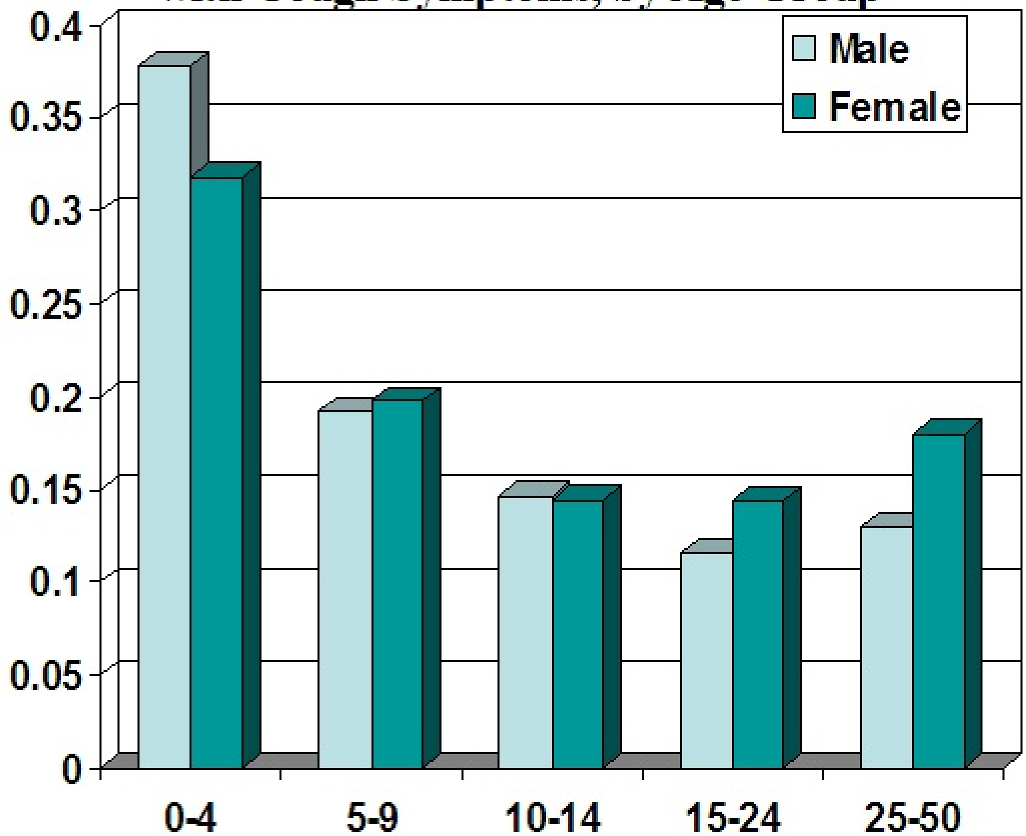

Figure 2: Mean Minutes per Day Spent in Cooking Chores, by Age Group and Gender

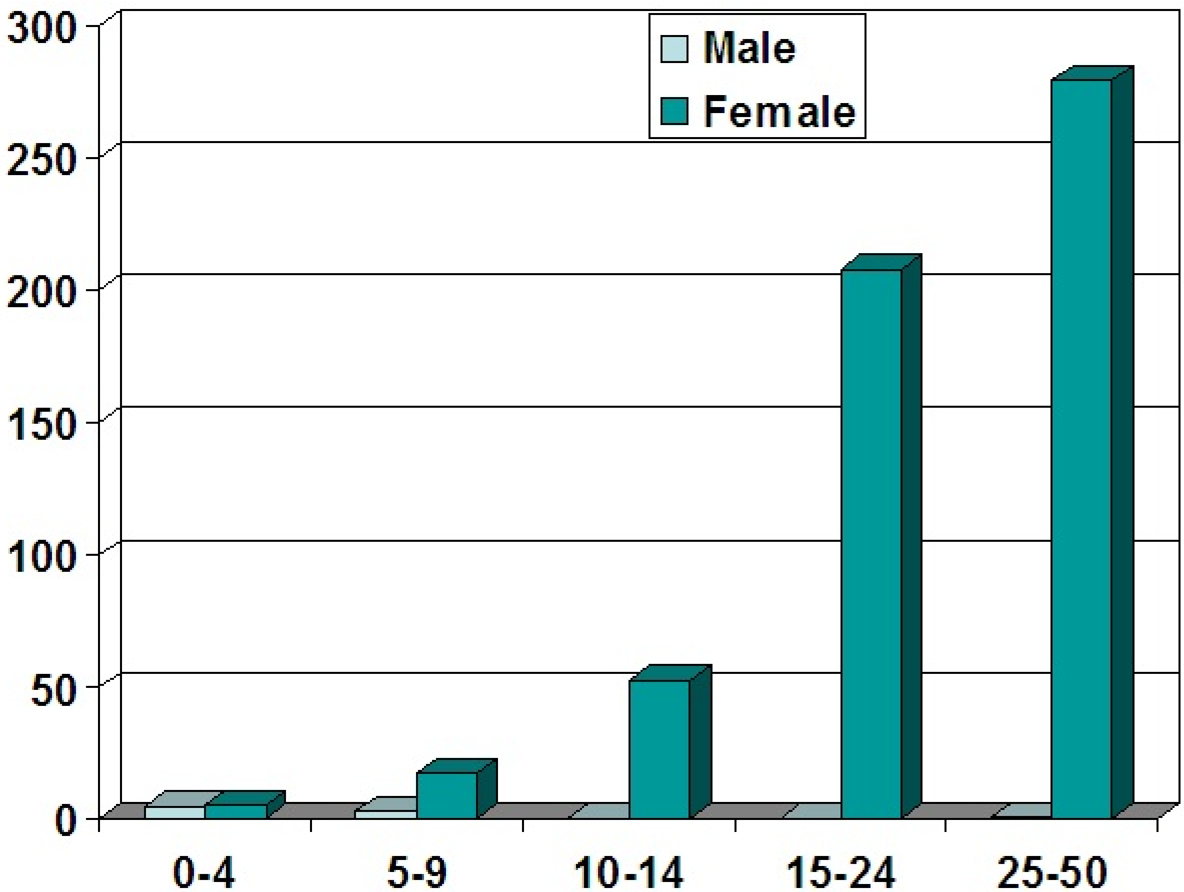

Figure 1a
Rural India, 1999: Household Distribution of Stoves

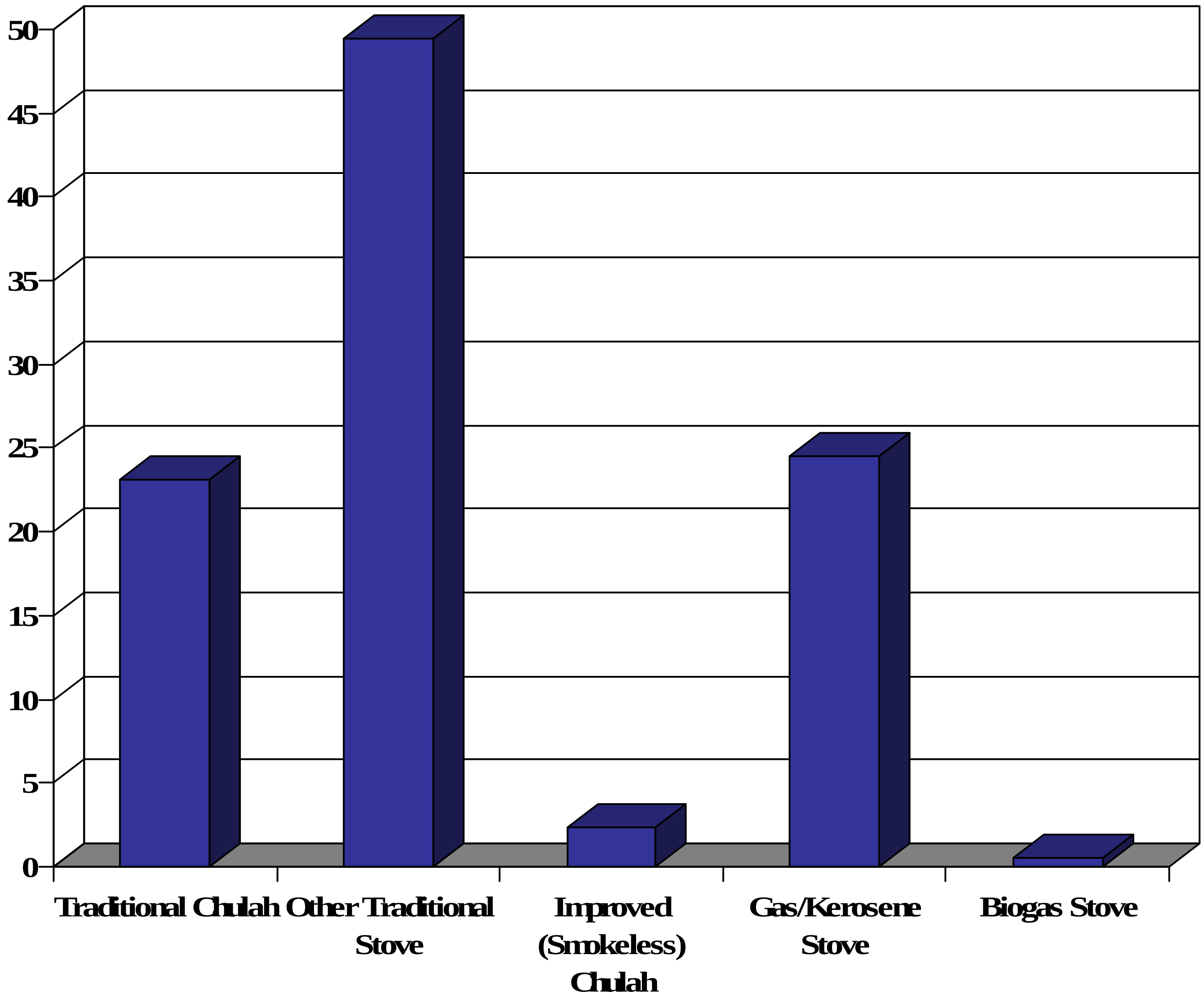

Figure 2a
Rural India, 1999: Mean Per-Household Expenditures (Including Imputed Self-Collected) on Fuel (Rupees)

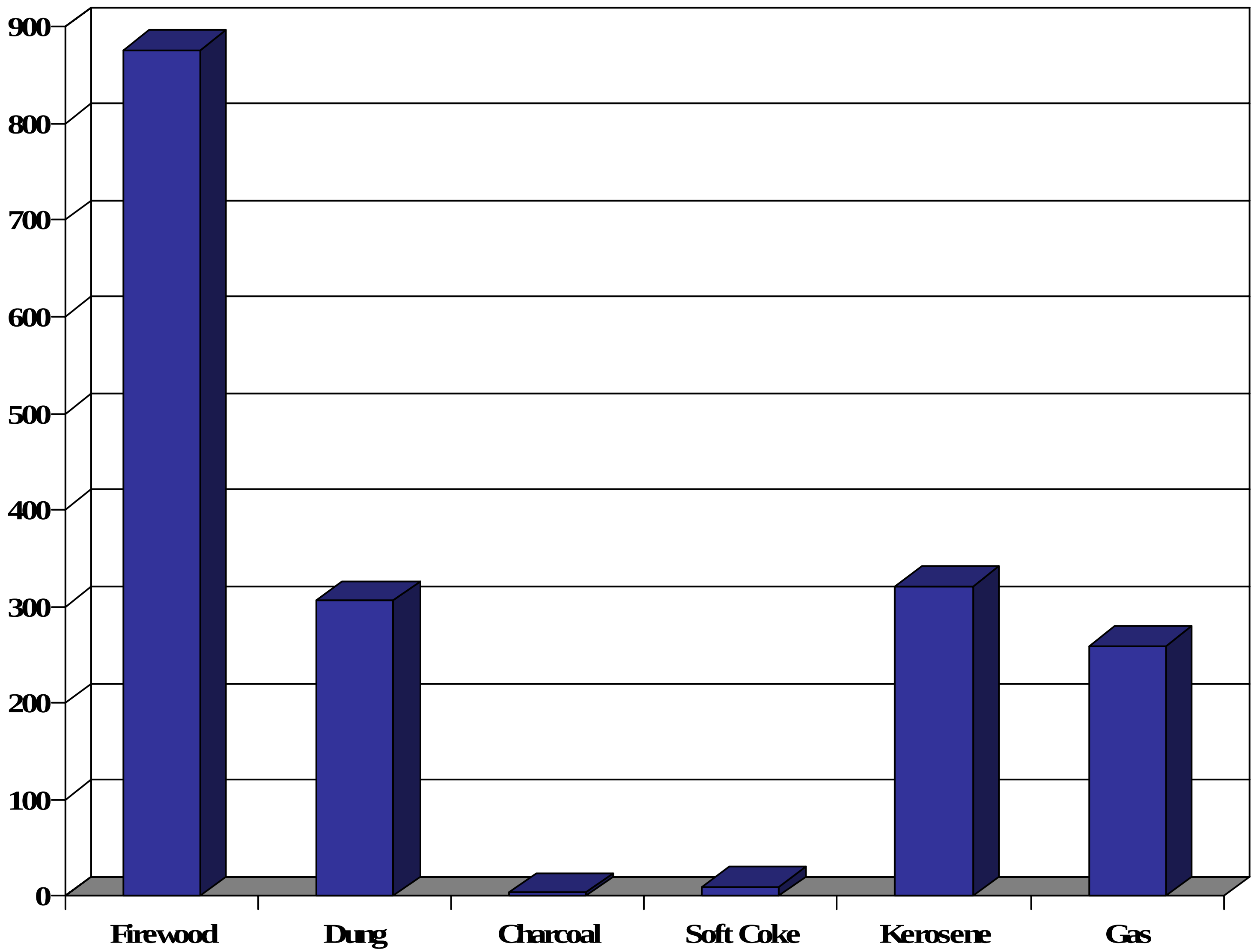

Figure 3a
Rural India, 1999: Percentage of Children with Respiratory Illness in the Past Year, by Age and Stove Type

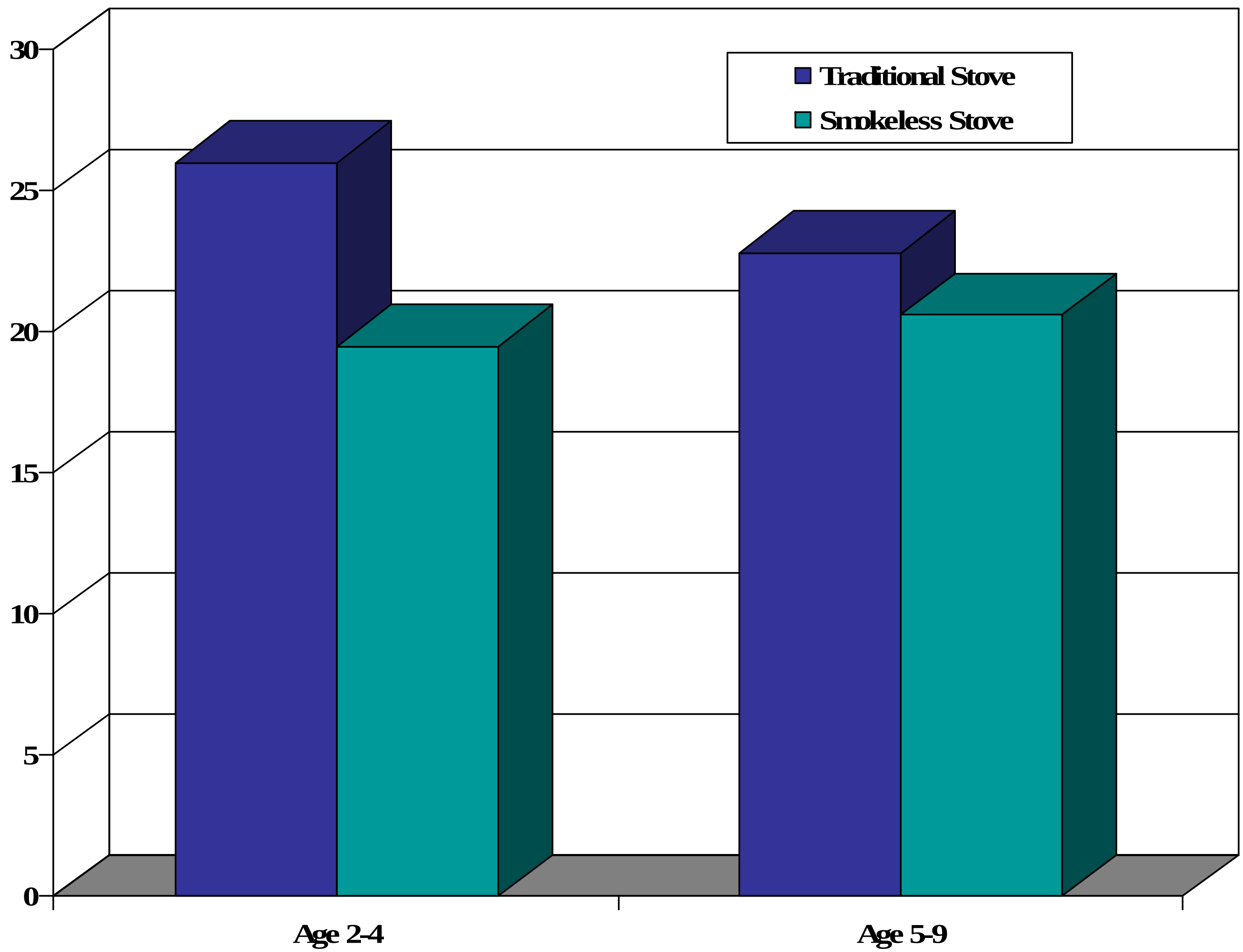

Figure 4a
Rural India, 1999: Percentage of Households with Chimneys and Kitchen Windows, by Stove Type

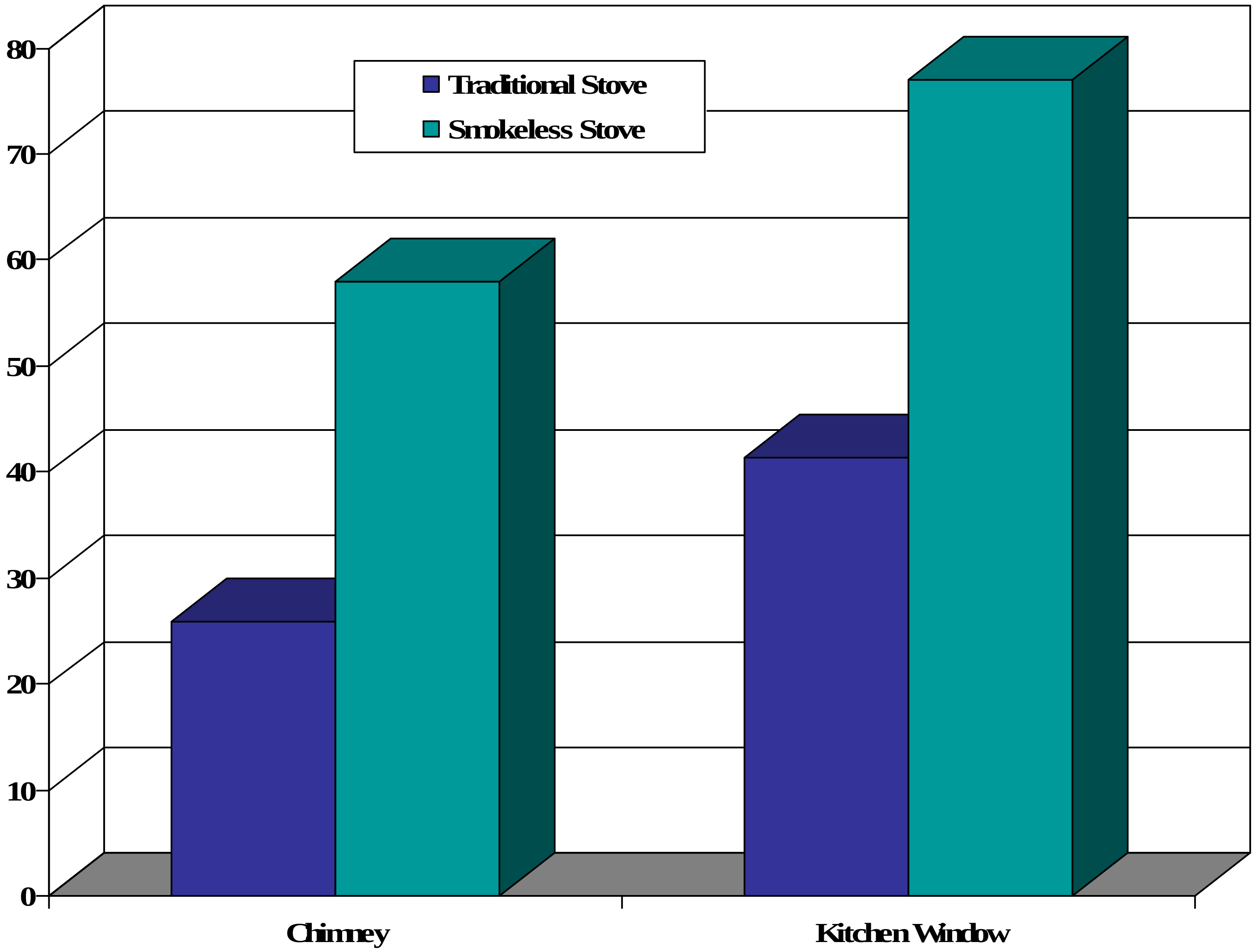

Table 1

Sample Characteristics

Variable	All Adults Aged 16+	Children 2-9
Respiratory symptoms	.154	.221
	(.361)	(.415)
Intestinal symptoms	.0489	.0694
	(.216)	(.254)
Age	36.0	6.09
	(15.8)	(1.98)
Education (years)	3.51	.515
	(4.14)	(.939)
Female	.477	.485
	(.500)	(.500)
Mother with children<5	.242	-
	(.563)	
Mother with children<10	.418	-
	(.857)	
Wife of head	.278	-
	(.448)	
Daughter-in-law of head	.0517	-
	(.221)	
Total hh expenditures (taka per month)	4797	4558
	(4176)	(4856)
Permeable roof	.205	.224
	(.403)	(.417)
Permeable walls	.326	.377
	(.469)	(.484)
Kitchen outdoors	.262	.292
	(.440)	(.455)
Number of individuals	4026	1365
Number of households	1198	780

Table 2

The Effects of Cooking Time on the Incidence of Respiratory Symptoms, All Adults and Women Only, by Estimation Procedure

	All Adults Aged 16+			Women Aged 16+		
	(1)	(2)	(3)	(4)	(5)	(6)
Estimation procedure	RE	FE-Household	FE-IV	RE	FE-Household	FE-IV
Cooking time ($x10^{-3}$)	.152	.0871	.349	.159	.170	.455
	(2.77)	(1.56)	(2.72)	(2.68)	(2.51)	(2.58)
Age	.00107	.00113	.00146	.00069	.00178	.00284
	(2.84)	(2.77)	(3.37)	(1.12)	(2.41)	(2.96)
Education	-.00357	-.00106	-.00011	-.00276	.00465	.00892
	(2.09)	(0.50)	(0.05)	(0.95)	(1.14)	(1.87)
Female	.00093	.0157	-.046	-	-	-
	(0.06)	(0.92)	(1.43)			
Total expenditures ($x10^{-5}$)	-.380	-	-	-.511	-	-
	(1.88)			(1.78)		
Permeable roof	-.0115	-	-	-.0384	-	-
	(0.66)			(1.59)		
Permeable walls	.00225	-	-	.0125	-	-
	(0.15)			(0.59)		
Kitchen outdoors	.015	-	-	.00948	-	-
	(0.94)			(0.42)		
Number of individuals	4590	4590	4590	2202	2202	2202
Number of households	1371	1371	1371	1368	1368	1368

Table 3

FE-IV Estimates: The Effects of Cooking Time on the Incidence of Intestinal Symptoms, All Adults and Adult Women Only

Variable	All Adults	Women
Cooking time ($x10^{-3}$)[a]	.0391	.0852
	(0.49)	(0.76)
Age	.000755	.000808
	(2.80)	(1.32)
Education	.00108	.000748
	(0.80)	(0.25)
Female	-.00226	-
	(0.11)	
Number of individuals	4590	2202
Number of households	1371	1368

[a]Endogenous variable. First-stage estimates given in Table 4, column 2.

Table 4

First-Stage FE-Household Estimates: The Determinants of Cooking Time and Calories Consumed

	Cooking Time		Calories	
Estimation procedure	(1)	(2)	(3)	(4)
Age	-1.33	-.792	-.178	.129
	(10.2)	(6.73)	(0.20)	(0.14)
Education	-3.43	-2.13	-10.7	-9.18
	(4.72)	(3.35)	(2.22)	(1.90)
Female	256.3	160.1	-728.8	-843.6
	(72.2)	(33.8)	(30.9)	(23.5)
Wife of head	-	144.8	-	129.0
		(28.0)		(3.28)
Daughter-in-law of head	-	197.6	-	-163.3
		(5.47)		(0.80)
Wife x number of daughters-in-law in the household	-	-67.3	-	104.0
		(10.2)		(2.08)
Daughter-in-law x Number of daughters-in-law	-	-19.0	-	10.3
		(1.79)		(0.13)
Daughter-in-law x Is there wife of head?	-	-35.4	-	460.3
		(1.58)		(2.70)
R^2	.640	.720	.168	.168
F-statistic (5, 2647)	-	171.5	-	5.67
Number of individuals	4026	4026	4026	4026
Number of households	1371	1371	1368	1368

Table 5

FE-IV Estimates: The Effects of Cooking Time and Calories on the Incidence of Respiratory Symptoms, Body Weight and the Incidence of Intestinal Symptoms

Dependent Variable	Respiratory Symptoms	Body Weight (kg)	Intestinal Symptoms
Cooking time ($x10^{-3}$)[a]	.392	11.5	-.00296
	(2.35)	(3.09)	(0.02)
Calories consumed ($x10^{-3}$)[a]	.00467	7.78	.170
	(0.04)	(2.92)	(2.01)
Age	.00156	.0217	.000787
	(3.10)	(1.89)	(2.10)
Education	.00205	.245	.00398
	(0.75)	(3.98)	(1.97)
Female	-.0671	-5.22	.128
	(0.57)	(2.07)	(1.50)
Number of individuals	3878	3878	3878
Number of households	1371	1371	1371

[a]Endogenous variable. First-stage estimates given in Table 4, column 2.

Table 6

FE-IV Estimates: Do House Materials or Kitchen Location Ameliorate the Effects of Cooking Time on the Incidence of Respiratory Symptoms?

All Adults and Women Only

	(1) All Adults Aged 16+	(2) Women Aged 16+
Cooking time ($x10^{-3}$)[a]	.418	.343
	(2.89)	(1.59)
Cooking time x permeable roof ($x10^{-3}$)[a]	-.0857	.638
	(0.78)	(1.47)
Cooking time x permeable walls ($x10^{-3}$)[a]	.0517	.0634
	(0.52)	(0.16)
Cooking time x kitchen outdoors ($x10^{-3}$)[a]	-.0212	-.0183
	(0.20)	(0.03)
Age	.00168	.00336
	(3.66)	(2.94)
Education	.000749	.0122
	(0.32)	(2.08)
Female	-.0506	-
	(1.46)	
Test statistics, no house effects $\chi^2(3)$,(p-value)	0.93, (.818)	2.43 (.488)
Number of individuals	4590	2202
Number of households	1371	1368

[a]Endogenous variable. See text.

Table 7

The Effects of Mother's Cooking Time on the Incidence of Respiratory and Intestinal Symptoms of Her Children 2-9, by Estimation Procedure

	Respiratory Symptoms			Intestinal Symptoms		
Estimation procedure	FE-Household	FE-Household	FE-Mother	FE-Household	FE-Household	FE-Mother
Mother's cooking time ($x10^{-3}$)	.608	.524	-	-.0909	-.102	-
	(1.93)	(1.65)		(0.38)	(0.42)	
Cooking time x Child<5 ($x10^{-3}$)	-	.311	.460	-	.0415	.00858
		(1.55)	(2.19)		(0.27)	(0.05)
Child age	.0241	.119	.173	-.0114	.0012	.-.0121
	(0.52)	(1.55)	(2.18)	(0.32)	(0.02)	(0.20)
Child age squared	-.00404	-.0105	-.0143	.000461	.000395	.000633
	(1.06)	(1.86)	(2.47)	(0.16)	(0.09)	(0.14)
Child female	-.0595	-.0594	-.0541	-.0142	-.0141	-.0303
	(1.93)	(1.93)	(1.72)	(0.60)	(0.60)	(1.28)
Mother's education	.0149	.0152	-	.0319	.0320	-
	(0.59)	(0.61)		(1.67)	(1.67)	
Number of children	1365	1365	1365	1365	1365	1365
Number of mothers	889	889	889	889	889	889

Table 7a
Conditional Logit Estimates: Effects of Maternal Household Work Specialization, Cooking Fuel and Venting on the Incidence of Respiratory Symptoms for her Children 2-9

Variable/estimation procedure	FE-Household	FE-Household	FE-Mother	FE-Mother	FE-Mother
Mother at home	.444 (1.18)	-.261 (0.34)	-	-	-
Mother at home x traditional biomass stove	-	.947 (1.07)	-	-	-
Mother at home x child aged 2-4	-.0446 (0.24)	-.289 (1.36)	-.279 (1.24)	-.279 (1.24)	-.279 (1.24)
Mother at home x child aged 2-4 x biomass stove	-	.435 (2.13)	.423 (1.95)	.549 (2.36)	.509 (1.79)
Mother at home x child aged 2-4 x biomass stove x chimney	-	-	-	-.485 (1.38)	-.437 (1.15)
Mother at home x child aged 2-4 x biomass stove x kitchen window	-	-	-	-	-.0411 (0.12)
Mother at home x child aged 2-4 x biomass stove x thatch roof	-	-	-	-	.163 (0.48)
Child aged 2-4	-.0906 (0.46)	-.0796 (0.40)	-.0859 (0.42)	-.0886 (0.43)	-.0868 (0.42)
Age of child	- .00727 (2.57)	-.00727 (2.56)	-.00805 (2.72)	-.00812 (2.74)	-.00808 (2.72)
Age of mother	.357 (2.40)	.369 (2.53)	-	-	-
Age of mother squared	- .00530 (2.33)	-.00548 (2.44)	-	-	-
Number of mothers	4468	4468	2431	2431	2431
Number of observations	2503	2503	2070	2070	2070

Absolute value of robust t-statistics in parentheses.

Table 7b
Conditional Logit Estimates: Effects of Maternal Household Work Specialization, Cooking Fuel and Venting on the Incidence of Intestinal Symptoms for her Children 2-9

Variable/estimation procedure	FE-Household	FE-Household	FE-Mother	FE-Mother	FE-Mother
Mother at home	-.593 (0.69)	12.6 (11.2)	-	-	-
Mother at home x traditional biomass stove	-	-13.8 (9.86)	-	-	-
Mother at home x child aged 2-4	-.462 (1.11)	-.567 (1.16)	-.263 (0.50)	-.263 (0.50)	-.262 (0.50)
Mother at home x child aged 2-4 x biomass stove	-	.154 (0.36)	-.00616 (0.01)	-.0270 (0.06)	-.152 (0.24)
Mother at home x child aged 2-4 x biomass stove x chimney	-	-	-	.221 (0.23)	-.102 (0.10)
Mother at home x child aged 2-4 x biomass stove x kitchen window					.446 (0.61)
Mother at home x child aged 2-4 x biomass stove x thatch roof					-.0216 (0.03)
Child aged 2-4	.346 (0.75)	.360 (0.78)	.398 (0.84)	.400 (0.85)	.389 (0.82)
Age of child	-.0136 (2.05)	-.0136 (2.05)	-.00809 (1.18)	-.00804 (1.17)	-.00831 (1.20)
Age of mother	.237 (1.18)	.247 (1.21)	-	-	-
Age of mother squared	- .00326 (1.08)	-.00333 (1.07)	-	-	-
Number of mothers	4468	4468	2431	2431	2431
Number of observations	596	596	454	454	454

Absolute value of robust t-statistics in parentheses.

Table 8

Who Cooks? The Determinants of Cooking Time, All Adults and Women Only, by Estimation Procedure: Full Sample

	All Adults Aged 16+		Women Aged 16+	
Estimation procedure	RE	FE-Household	RE	FE-Household
Age	-.551	-.566	-1.59	-2.11
	(6.36)	(4.80)	(7.14)	(5.68)
Education	-1.46	-2.01	-4.31	-7.46
	(4.29)	(3.36)	(4.46)	(3.87)
Female	139.2	144.1	-	-
	(24.90)	(30.32)		
Mother with children<5	-11.3	-22.8	-14.6	-54.7
	(1.77)	(3.72)	(2.20)	(3.64)
Mother with children<10	26.9	37.4	24.3	59.1
	(5.85)	(8.53)	(5.16)	(5.42)
Wife of head	126.1	117.7	128.7	95.5
	(15.07)	(19.5)	(13.77)	(7.58)
Daughter-in-law of head	80.8	132.7	55.38	103.4
	(2.31)	(5.47)	(1.49)	(1.77)
Number of daughters-in-law	-3.89	-	-20.76	-
	(2.05)		(1.68)	
Wife x number of daughters-in-law in hh	-52.5	-55.4	-31,71	-19.9
	(5.16)	(8.21)	(1.99)	(0.98)
Daughter-in-law x Number of daughters-in-law	-4.28	-25.44	9.44	-14.44
	(-0.36)	(2.59)	(0.53)	(0.54)
Is there a wife of head?	-20.58	-	-53.13	-
	(3.91)		(4.37)	
Daughter-in-law x Is there wife of head?	-17.27	-35.8	7.92	-10.99
	(0.58)	(1.84)	(0.25)	(0.21)
Total hh expenditures (x10^{-5})	127.8	-	293.9	-
	(3.63)		(3.26)	
Permeable roof	5.53	-	10.3	-
	(1.76)		(1.63)	
Permeable walls	-5.24	-	-11.32	-
	(1.98)		(2.07)	
Kitchen outdoors	2.95	-	3.56	-
	(1.02)		(0.59)	
Number of individuals	4590	4590	2202	2202

Number of households	1371	1371	1368	1368

Table 8a
Conditional (FE-Household) Logit Estimates:
Determinants of Household Work Specialization Among Married Women 15-59

Variable	(1)	(2)	(3)
Number of children < 5	.134	.365	.365
	(1.36)	(1.96)	(1.96)
Number of children <5 x biomass stove	-	-.297	-.313
		(1.49)	(1.52)
Number of children <5 x biomass stove x chimney	-	-	.0782
			(0.34)
Age	-.183	-.183	-.183
	(5.63)	(5.64)	(5.63)
Age squared	.00246	.00246	.00247
	(5.75)	(5.74)	(5.74)
Relationship to household head (left out = wife)			
Daughter-in law	.652	.628	.631
	(2.42)	(2.33)	(2.34)
Daughter-in-law of oldest son	-.480	-.472	-.470
	(2.48)	(2.44)	(2.42)
Sister-in-law	.928	.914	.912
	(2.50)	(2.46)	(2.45)
Mother	1.21	1.19	1.18
	(2.94)	(2.88)	(2.85)
Number of mothers	10471	10471	10471
Number of observations	1245	1245	1245

Absolute value of robust t-statistics in parentheses.

Table 9

Who Cooks? Within-Household Determinants of Cooking Time, All Adults and Women Only: Panel Sample with Endowments

	All Adults Aged 16+	Women Aged 16+
Age	-.596	-2.82
	(2.01)	(2.14)
Education	-.615	-6.04
	(0.40)	(0.96)
1982 health endowment	-60.9	-140.1
	(2.77)	(1.85)
Female	167.7	-
	(13.91)	
Mother with children<5	-11.78	65.6
	(0.51)	(0.98)
Mother with children<10	42.93	12.31
	(3.11)	(0.29)
Wife of head	77.2	86.9
	(5.11)	(2.17)
Daughter-in-law of head	-3.44	-155.6
	(0.01)	(0.31)
Wife x number of daughters-in-law in hh	-26.7	-5.96
	(2.18)	(0.13)
Daughter-in-law x number of daughters-in-law	81.73	160.48
	(0.47)	(0.51)
Daughter-in-law x Is there a wife of head	-247.14	-152.9
	(0.92)	(0.29)
Number of individuals	922	371
Number of households	449	291

Table A
Logit and Conditional Logit Estimates:
The Effects of the 1982 Health Endowment on the Probability of Death by 2002,
Panel Sample with Endowments

Estimator	Logit	Conditional Logit: Village FE	Conditional Logit: HH FE
Age in 1982	.0653	.0655	.0589
	(12.8)	(13.6)	(10.1)
1982 health endowment	-1.33	-1.45	-1.44
	(2.95)	(3.07))	(2.45)
Female	-.0459	-.0408	-.149
	(0.27)	(0.23)	(0.73)
Household head literate - 1982	-.355	-.324	-
	(2.01)	(1.66)	
Land owned - 1982	.000108	.0001	-
	(0.35)	(0.02)	
Household income - 1982 ($x10^{-3}$)	-.108	-.130	-
	(0.76)	(0.83)	
Number of individuals	1539	1539	727