Short- and Long-Term Health Effects of Burning Biomass in the Home in Low-Income Countries

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I. Introduction

In assessing the determinants of poor health and mortality in developing countries, an important factor that has been relatively neglected 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). Exposure to IAP from the combustion of solid fuels has been hypothesized to be a major 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). Global mortality from IAP is 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 ARI a leading cause of deaths in developing countries, but exposure to smoke during childhood can potentially have long-term consequences. Lungs typically grow to full capacity during the teen years. The deficits in the lung function of younger 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).

The existing evidence on the relationship between IAP and health is far from conclusive, however, and has three major deficiencies. First, most of the evidence is based on associations; e.g., comparisons of health across households using different fuels or stoves. If fuel type is a choice correlated with unmeasured health inputs, such evidence cannot be considered causal. Almost none of the existing studies considers the choice of fuels, stove locations or stove types. Attempts to deal with heterogeneity are limited to controlling for measured household attributes such as income. 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.

Studies randomly assigning smokeless stoves across households remedy the problem of endogenous fuel/stove choice. These experimental studies (e.g., Tone Smith-Sivertsen *et al.* (2004)) identify the average household health effects of reducing indoor smoke on individuals (intent-to-treat). However, the health effects of IAP are not likely to be evenly distributed within a household. This is because pollutants are heavily concentrated at the source - the stove. Thus, stove proximity is a major determinant of pollutant exposure. Field studies in rural Kenya by Ezzati, Saleh, and Kammen (2000) and Ezzati and Kammen (2001), for example, based on in-home monitors capable of detecting airborne respiratory particles less than 10 microns (PM_{10}) and 2.5 microns ($PM_{2.5}$) 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.[1] Moreover, based on person-specific monitors they also found that high-intensity episodes contributed only 0% - 11% of the total exposure of household members who do not take part in cooking.

The individual health effects of IAP thus depend on the allocation of a person's time to cooking. If this allocation is mainly determined by simple observables, such as gender, then it would be relatively straightforward to measure with household-level experimental interventions individual health effects with stratification by gender and age. However, extended families are the norm in many low-income countries where IAP is a major problem. For example, in the sampled Bangladesh households that we study almost half (48%) have more than one adult woman. And, the burden of cooking is not evenly distributed across the women in these multiple-women households - in over 32% of the multiple-women households one woman accounts for over 90% of total cooking time; in over half one woman accounts for at least 70% of the cooking burden. The distribution of the individual effects of stove/fuel interventions will thus be heterogenous across households, and will depend on the non-random allocation of tasks. Exposure to IAP, associated with the assignment of tasks, may also be endogenously determined - related to inherent healthiness and possibly associated with other inputs that affect health

[1]In comparison, the California Air Resources Board has set an indoor air quality standard of 50 $\mu g/m^3$.

outcomes. For example, women who are assigned cooking tasks may also receive the lowest priority in food allocations or in access to health care.

It is important to note that because a person's exposure to particulates depends on both the person's activities (proximity/time) and the particulates emitted from the stove, a randomized stove intervention may not alone be sufficient to identify particulate exposure effects. For example, the stove variable cannot be used as a single instrument for exposure if the stove intervention affects both the emissions of the point source and the allocation of time (even if there is no effect of the stove on cooking efficiency) and the re-allocation of time has independent effects on own or child health, net of exposure to particulates. In our model, for example, reductions in health-depleting emissions from the stove affect the division of time among women and increase income.[2] If inputs other than particulates affect health, then there are time, particulate exposure and income effects on health associated with a reduction in emissions. To identify particulate exposure effects requires more instruments than stove variation unless it is assumed that no other factors affect respiratory health. We will assess whether food consumption and the mother's time at home are also determinants of respiratory health.

A third deficiency of the existing studies of the health effects of IAP is that there is little information on the longer-term effects of exposure to indoor pollutants. IAP studies showing that new-borns have lower birthweights in households burning biomass are suggestive of long-term fetal effects, but these studies again do not take into account that fuel use, stove types and/or ventilation may be correlated with other factors determining birthweight and health. And, experimental interventions have not yet been of sufficient length to measure such long-term intergenerational effects.[3] Assessing such effects is particularly difficult because, for the reasons discussed, children within extended households, even children with the same mother, are likely to have different exposures to pollutants depending on whether and when their mothers were assigned cooking duties, a possibly endogenous choice.

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[2]In particular, the model and our data suggest that the introduction of clean fuel or smokeless stoves would lead to a more equitable burden of cooking across women.

[3]In the design of the Guatemalan randomized stove intervention study (Tone Smith-Sivertsen *et al*. (2004)) the assessment of youngest children at baseline terminates when they are only 18 months of age.

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 IAP 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 (2009)). None of these studies look at long-term effects, although there is a recent literature revealing long-term health effects due to early-childhood and pre-natal disease exposure and nutritional deficiencies (e.g., Maccini and Yang (2009) and Bleakley (2010)). In large part the lack of evidence of the short-term and long-term health effects of IAP is due to data deficiencies. Relating individual health to particulate concentrations in the home requires information on the intra-household allocation of time. Moreover, if the allocation of time is related to the allocation of other health inputs, such as nutrients, information is also needed on food intakes at the individual level and a framework for studying these allocations is needed, as in the literature reviewed by Behrman (1997).[4]

In this paper we exploit the extended family structure of South Asian households and information on social hierarchies using new survey data on the health and time allocation of individuals in rural households in both Bangladesh and India to investigate how and to what extent the division of household responsibilities, household structure, nutritional intake, the physical attributes of the house, fuel choice and stove types affect child and adult health contemporaneously and over the longer term, given heterogeneity and household optimizing behavior. IAP levels in rural areas of both countries are very high.[5]

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[4] In a review of the limited studies examining the pollution "microenvironment," Ezzati and Kammen (2002, p. 1059) conclude 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."

[5] Dasgupta *et al.* (2004a), for example, find that concentrations of 300 μg/m^3 or higher are common in Bangladeshi households. A recent study (and accompanying editorial) published in the *New England Journal of Medicine* (Gauderman *et al.,* 2004) finds striking associations between air pollution and lung development and function measured annually for eight years among children 10-18 years of age in California, where particulate concentrations are far lower than in Bangladesh.

The data set we use from Bangladesh, from the 1981-82, 2002-2003 and 2007-8 Nutrition Surveys, provides detailed panel information for rural households on the time allocation, nutrient intakes and health symptoms of all family members across a 24-hour period; on the location of kitchen facilities; on proximity of children to mothers while cooking; and on features of house construction. The latest round of the survey indicate that over 92% of Banghladesh rural households still use biomass as their primary fuel for cooking.[6] We use these data (i) to assess to what extent, if at all, individual exposure to cooking-related smoke causally affects health when there is health heterogeneity, (ii) to assess the efficacy of improved ventilation associated with construction materials, (iii) to identify to what extent the omission of such other health inputs as nutrient consumption biases estimates of IAP health effects.

The data sets from India, the 1982 and 1999 Rural Economic and Demographic Surveys (REDS 1982 and 1999) cover the entire rural population of India and include households using different fuels and stove types. Most importantly, the two Indian surveys constitute a panel so that it is possible to infer for children in the 1999 round their exposure to IAP throughout their childhood. The Indian data sets contain detailed information on the time allocation of women but only information on health symptoms for children and no information on individual food consumption. We demonstrate using the Bangladesh data that this latter omission does not bias inferences about the respiratory effects of IAP, although it food consumption does affect at least one other major non-respiratory health symptom. We thus use the India data to estimate (i) how fuel and stove type along with their mother's proximity to the pollution point source, and mothers proximity to their children, contemporaneously affects children's respiratory health, by age and (ii) how maternal exposure to IAP for a child from its from conception to age 5 affects the child's health symptoms at later ages.

Consistent with our simple model of task allocations in the household we find that women with lower health endowments are assigned cooking tasks. Our identification strategy for quantifying the effects of exposure to smoke via cooking on respiratory health in part exploits the extended family structure, making use of detailed contemporaneous and retrospective

[6]Table A in the Appendix provides the distribution of fuels used for cooking in seven categories and by frequency of use from primary to tertiary.

information on the status ranking of individuals in the household based on their relationship to the household head. We show that, consistent with the anthropological literature on rural South Asian households, a woman's household rank is also a strong determinant of her chore assignments, in particular whether a woman takes on household cooking tasks, net of her schooling and age and her endowed health. A potential problem with this identification strategy is that household rank may also affect health other than through the allocation of tasks. Indeed, we show that rank affects the allocation of individual food intakes, which also affect some health symptoms. We thus also control for this endogenous variable that also potentially affects health.

We assess the success of our identification strategy by carrying out a number of tests and contrasts. In addition to performing formal over-identification tests, along with assessments of their power, we first show that household rank does not affect access to health care, conditional on illness. We also show that smoke exposure does not affect non-respiratory illnesses, which would not be the case if rank affected health generally or was determined by overall health. Second, we exploit the fact that households differ in their use of fuels and show that cooking time, net of household fixed-effects, affects respiratory symptoms only within households using bio-fuels net of a household fixed effect; we can find no effect of cooking time within households using clean fuels or improved stoves using the same identification strategy. This would not be the case if cooking assignments were based on respiratory healthiness. Third, in addition to the estimates obtained using instrumental variables applied to within-household differences in smoke exposure, we carry out within-mother estimates to identify longer-term child exposure effects, which control perfectly for heterogeneity across mothers. All of the estimates point to cooking assignments producing significant respiratory symptoms for the adults who perform them and contemporaneously and persistently in later life for their youngest children when bio-fuels are used.

In section II of the paper we set out a simple multi-person model of household time allocation incorporating health heterogeneity to guide the empirical specifications and to highlight the determinants of who cooks when households cannot substitute away from biomass fuels. The model delivers the results that specialization in cooking is more likely to occur in households burning biomass, and therefore the necessity of rules allocating this health-depleting chore among women, and that heterogeneity in inherent healthiness will affect which individuals cook, one source of endogenetic bias. Section III of the paper contains a description of the data sets and descriptive statistics. In section IV we set out our econometric strategies to identify contemporaneous own health effects of exposure to IAP associated with cooking time and food intake, which exploit the extended family structure and social hierarchies within the household, and report the estimates of (i) how household rank and health endowments affect who cooks and (ii) how cooking time and individual food consumption, and thus stove proximity, causally affect the incidence of respiratory and intestinal symptoms.

In section V we examine intergenerational contemporaneous exposure effects, estimating how the mother's cooking time contemporaneously affects her child's health, again taking into account individual health heterogeneity across households and individual women (mothers). We find in both data sets contemporaneous effects of maternal exposure to indoor pollutants on children in bio-mass burning households but not in clean-fuel households. Section VI is concerned with identifying the longer-term health effects of a child's exposure to IAP. Based on re-constructed histories of maternal within-household status we estimate the mother's likelihood of being the households' principal cook at every child's age, from conception to age five and the effects of this on the current respiratory health of the child. The results indicate that a child whose mother is the principal cook when the child is in the womb and in her first year of life is significantly more likely to exhibit respiratory symptoms, given contemporaneous exposure, at age 5-9. As the data indicate that women in peak childbearing ages (and older women) specialize in home care, and cooking, the evidence thus suggests that households in assigning tasks among women trade-off the future well-being of their children for current income gain.

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

$$\textbf{(1)} \qquad U = U_m(H_m, X_m) + U_f(H_f, X_f)$$

where H_m=(h_{m1},h_{m2},...,h_{mJ}) is the set of health statuses of the J males in the household, H_f =(h_{f1},h_{f2},...,h_{fK}) is the set of health statuses of the K females in the household, and X_m =(x_{m1},x_{m2},...,x_{mJ}) and X_f=(x_{f1},x_{f2},...,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. In most households only women devote time to the cooking activity in our data, and so we will focus for simplicity on the household's allocation of women's time.[7] 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) $$h_{fi} = h_f(t_{ci}, x_{fi}) + \mu_{fi}, i = 1, K$$

(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). We assume that cooking time reduces health, given other health inputs because it increases exposure to the emission of particulates.

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}. Thus a reallocation of time away from cooking increases health and income. Households maximize the utility function (1) subject to (2), (4), the time constraints, and the budget constraint

[7]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.

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

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.

To fix ideas, 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, 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. For example, if 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. Moreover, 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 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, in this example with an additive health endowment, if $\mu_{f1}<\mu_{f2}$, the less healthy woman will be the one devoting more time to cooking. Thus, in this case 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. Most importantly, the model implies that a reduction in the health-depleting effects of cooking time will lead to a re-allocation of time that is likely more equitably distributed and an increase in income. Both of these effects may affect health apart from the direct reduction in the emissions of particulates.

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.[8] 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 (λ_{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 (λ_{fi}=0). If an important reason that cooking and child care are joint products is the 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.[9]

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-

[8]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}

[9]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.

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 to her daughter-in-law.

Fafchamps and Quisumbing (2003) 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 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 assess to what extent rank directly affects the allocation of other resources.

III. Data

The data for our analysis comes from two sets of panel surveys: the 1981-82, 2000-2003 and 2007-8 Nutrition Surveys of Bangladesh and the 1982 and 1999 Rural and Demographic Survey (REDS). The 2000-2003 Bangladesh survey sample has two components. It includes (i) a random sample of all households in 14 villages that was carried out in 2000, and (ii) the second round of 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. The 2007-2008 survey round followed all of the individuals in the preceding round, adding information on cigarette smoking, fuel use, and the proximity of children to mothers while the mothers are cooking in addition to the core individual-specific time and nutrient allocation data. 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. The questionnaires in the Bangladesh survey also elicited information on housing, including the location of the kitchen (outside or not) as well as roof and wall material. 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 (Dasgupta *et al*., 2004).

The time-activity information, measured in minutes, 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 for each adult in the sample. 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. We use the category "meal preparation" as the indicator of proximity to the stove. Given the almost universal prevalence of cooking with biomass in the sample, this proximity reflects exposure to a major source of smoke.

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 2000-2003 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. This is despite the fact that men are significantly more likely to smoke cigarettes than are women - in the 2007-2008 round, 31.4% of the men while only 12.5% of women reported smoking cigarettes at the time of the survey.

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 (Figure1) 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. In the 2007-2008 round of the data, we collected information on whether a mother, when she was cooking, was within “an arm’s length” of any of her children age less than eight. Appendix Figure A provides a lowess-smoothed plot of the relationship between the age of the child (in months) and the probability that the child was proximate to the mother when she was cooking, by time of day. The figure confirms that child proximity to the stove falls with age - peaking at age one, when evidently half of children at that age are close to their mother when she is cooking, and dropping monotonically after age one to zero at ages above six.

Finally, the time-allocation data from the Bangladesh survey also indicate the prevalence of specialization in cooking when there is more than one adult women. Figure 3 displays the household distributions of the share of “cooking” time in total household cooking time for the woman with the most number of minutes per day spent cooking for households with two (453 households) and three (155 households) adult women. As can be seen, in 50% of households with two women, the burden share exceeds 80% for one of the women; the median share for the cooking specialist in three-women households is 63%. 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 substantially more 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. Over 75% of the sample households in the Indian sample cook with a stove that uses biomass, 1/3 of those with a traditional chulah stove, and only a small subset (two percent) of those using biomass employ a stove that is designed to reduce smoke. The main alternatives to biomass as fuel - firewood, dung, charcoal, and soft coke - are kerosene and LPN gas. On average, these clean cooking fuels are 33% of average total expenditures on fuel used for cooking, inclusive of the value of home-collected or produced products.

The 1999 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 in this survey so that it is not possible to measure very well exposure to smoke using this information. There is also a principal activity question, which identifies those women whose principal activity is household work. Based on this variable, we can construct a measure of household specialization - if in households with more than one women none report that their principal activity is household work or all report household work as their principal activity, then there is no specialization. This crude measure, which likely understates the degree of specialization in cooking tasks, suggests nevertheless that over 20 percent of the households with more than one adult women exhibit household work specialization. More importantly, with these data we can assess whether in households using smoky fuels and traditional stoves specialization is more likely, as implied by the model.

Figure 4 reports the incidence of specialization by fuel/stove type and number of adult women per household in the data. As can be seen, for all household sizes, households burning biomass on traditional stoves are substantially more likely to be specialized compared with smokeless households. These differences in specialization by fuel/stove type are not due to differences in household wealth, average schooling levels of the women or the average number of children across household types. A regression of the specialization measure on fuel/stove type with these control variables included indicates a statistically significant difference in the likelihood of specialization - on average households burning biomass are 58% more likely to be specialized (t=6.23).

A second shortcoming of the Indian survey 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 intergenerational externalities that arise because of the proximity of young children to mothers who are themselves near a pollution source as in the Bangladesh data. With these data 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 conditional on a household fixed effect, which impounds household-level preferences for clean fuel.

There is also 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 using biomass fuel for cooking. Consistent with the Bangladesh data and with the closer proximity of the youngest children to mothers, Indian children 1-4 in such households are more likely to have cough symptoms reported by mothers than are children aged 5-9 - 26% versus 23%. Such symptoms are also more prevalent among households using biomass compared with households using clean fuels or smokeless stoves - among children 1-4 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 average 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

(9) $$h_{ij} = \alpha_t t_{ij} + \boldsymbol{\alpha_A A_{ij}} + \boldsymbol{Z}_j \boldsymbol{\alpha}_z + \boldsymbol{X}_j \boldsymbol{\alpha}_X + \mu_{hj} + \mu_{hij} + e_{hij},$$

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); $\boldsymbol{Z}_j$ is a vector of household-level smoke-related factors that reflect ventilation (permeability of walls and roof, and whether cooking is carried out outdoors); $\boldsymbol{X}_j$ 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 her respiratory health. The problem for estimation is that cooking time may be correlated with unmeasured household and individual-specific health variables, as our model suggests. 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 the within-household distribution of women's chores is related to the differences in individual health endowments, or if there is measurement error in the time exposed to smoke (t_{ij}) variable. The theoretical model presented in Section II 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 cook more. In both cases, 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 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 or is correlated with her health.[10] 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). However, a woman's status may also affect the allocation of other health-related resources to her. We test for that below.

B. Who Cooks? The Determinants of Cooking Time in Bangladesh

The estimation strategy to identify the causal effects of exposure to smoke through cooking in essence requires that we are able to account for the assignment of cooking within the household. The anthropological evidence suggests that relationships to the head matters for household tasks. The simple optimizing model, which assumes that individuals understand the health consequences of their activities but have no scope for fuel substitution, as in Bangladesh, will allocate unhealthy tasks to individuals, within the household ranks, who are for other reasons less capable of contributing to earnings, due to endowments or alternative responsibilities such as child-rearing.

Table 2 presents household random effect and fixed effects estimates of the determinants

[10]Women's tasks may also be assigned by whether or not they are caring for young children. To the extent that higher fertility reflects or affects health, the presence of a child is not a valid instrument.

of cooking time, for all household members and for all women aged 15 and above in the 2000-2003 Bangladesh survey round. These estimates establish three facts. 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 will be included among the set of variables used to identify the effects of smoke exposure have power in predicting time spent cooking beyond such variables as age and education. Both wives and daughters-in-law spend more time cooking than other women in the household, who are primarily daughters of the head. Second, mother's with children 5-9 years of age cook more, and mother's with children 0-4 cook less. Children in the youngest age group, as indicated in Appendix Figure A, 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. Households thus appear to avoid somewhat exposure effects for the youngest children. Older children (aged 5 - 9 years of age) are not as spatially close to their mother, 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 2 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. The FE point estimate for the women-only sample indicates that ten years of schooling reduces a woman's time spent cooking by nearly 75 minutes per day compared to an unschooled woman.

The results in Table 2 thus are consistent with a pattern of the allocation of women's tasks 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. The finding that less educated women cook more, although suggestive of efficiency-based specialization, however, does not necessarily mean that less healthy women cook. As noted earlier, the sign of the bias in α_t 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 the panel feature of and individual-specific food consumption in 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. The panel 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% of young women in 1981-82 had left the sampled villages. 97 percent of all surviving original sample subjects, and 96 percent of all surviving females were found and surveyed in the 2002-2003 round.

In Pitt *et al.* (1990), the 1981/82 household survey data were used to obtain a direct measure of the health endowment, μ_{hij}. 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 within the household 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 2000-2003? Appendix Table B presents logit and conditional legit 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 within the next twenty-year interval. 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.[11] To obtain within-household estimates moreover the effective

[11]The sample size of the 1981-82/2000-2003 panel is smaller than the 2000-2003 sample that we use for most of our analysis for two reasons. (i) Only a random half of the original survey households were administered a questionnaire eliciting information on individual-specific food intakes. Only for this subsample can endowments be estimated. (ii) The sample in 2000-2003 includes an additional set of randomly-selected households that were not part of the panel.

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 have 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 3 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=-2.84) 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.[12]

C. Estimates of Direct Exposure Effects on Adult Health

Table 4 provides estimates of α_t, the effect of cooking time, in minutes, on the incidence of respiratory and intestinal symptoms for all adults in the sample of households and for adult women only. Columns (1) and (5) present random-effects estimates for respiratory symptoms 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 (5). None of the ventilation measures that Dasgupta *et al.* (2004) suggest are

[12]In Pitt *et al.* (2010) within-round repeated information on intakes, activities and health outcomes for a sub-set of the households are used to estimate the magnitude of the measurement error in the endowment residuals and the biases in endowment effects. The former is estimated to be about 12%, and the absolute values of endowment coefficients were lower by about 9% depending on the dependent variable.

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 (6) 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, as indicated in Table 3, 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 (7) of Table 4, where the identifying 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.[13] 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, as seen in Table 2.[14] The FE-IV estimate 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 ($\alpha_1^{FE\text{-}IV}$ - α_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

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[13]We are able to enrich the set of hierarchical variables in the larger 2000-2003 Bangladesh sample compared to the panel because of the larger sample size. We do not use information on the ages and presence of children to identify exposure effects, however, as these may be endogenous variables. They are included in the specifications reported in Tables 2 and 3 to characterize the allocation rules within the household. We report the first-stage estimates below.

[14]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, where we present first-stage estimates for the augmented specification including calorie consumption.

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 II and the estimated health endowment effect in Table 3 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 (6) results suggests that measurement error is the predominant source of bias.

C. Diagnostics and Robustness Checks

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 and with the results reported in Table 2, that the hierarchy of women by marital status and relationship to the head affects time allocation, but also that this status in the household has no other effects on health. One means of testing this directly is to carry out over-identifications tests. 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 for respiratory symptoms in Table 4. 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):

$$\textbf{(11)} \qquad d_{ij} = \beta_t t_{ij} + \boldsymbol{\beta_A A_{ij}} + \boldsymbol{Z_j \beta_z} + \boldsymbol{X_j \beta_X} + \mu_{dj} + \mu_{dij} + e_{dij},$$

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 $\beta_t > 0$.

Intestinal symptoms are the second-most prevalent set of symptoms reported by respondents, with almost 5 percent of adults (7 percent of children) reporting having had such symptoms in the two weeks prior to the survey. In the fourth and eighth columns of Table 4 we present 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. In both samples, the estimated effects of cooking time are small and statistically insignificant.[15] The finding of β_t=0, however, is consistent with, but not sufficient to establish, the validity of our FE-IV procedure.[16] Because the incidence of intestinal symptoms is also relatively small, in percentage terms the β_t point estimates suggest that the four-hour per day increase in cooking time would increase the incidence of such symptoms by a relatively large percentage. However, the over-identification *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.

Consistent with the specification of the production function for health (2) in the model, we thus add to the respiratory and intestinal symptom equations an additional endogenous input -

[15]The results are similar for the fixed and random-effects estimates, which are available from the authors.

[16]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.

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. Calorie consumption was not obtained for all household members, so that sample size drops by about 15% when this variable is included in the analysis.[17]

The allocation of calories in the household is also a choice, and appears to be significantly, but less strongly, related to the hierarchy variables. The first four columns of Table 5 report for the full sample of adults the first-stage equations for both cooking time (used in obtaining the estimates in Table 4) 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 for task allocation are consistent with the South Asian anthropological literature.

The fact that household rank marginally affects calorie consumption raises the possibility that rank may also affect other variables directly affecting health. Lower rank may simply mean reduced access to all inputs, some of which also affect health. However, the allocation of calories may simply reflect the allocation of tasks - if cooking is a more sedentary activity than other activities, then those who cook would rationally consume less calories (see Pitt *et al*. (1990)). For four of the five hierarchy variables the signs of rank coefficients across the calories and time equations are opposite, consistent with this. And we show below evidence consistent with cooking time requiring less calories compared with the average of all other activities.

We can assess whether the household hierarchy affects health-related variables that are not directly related to task allocations by also examining the determinants of the use of medical services. The data provide for each symptom whether or not the individual sought care from a medical provider. On average a person with a symptom obtained care 45% of the time. The last

[17]The first- and second-stage estimates and inferences are similar for the full and reduced samples when calories are excluded. All estimates are available from the authors.

two columns of Table 5 report the estimates of the effects of the rank variables on the probability of obtaining medical care for those individuals with any illness symptoms. The regressions includes the full set of symptom dummy variables. As can be seen, for given symptom type, the set of rank variables is not statistically significantly related to the use of medical services. Women who cook do not receive less preferential access to health care, conditional on illness.

Table 6 reports the estimates of the effects of cooking time on respiratory symptoms, on body weight, on the intestinal symptoms and on two other sets of symptoms - fever (unrelated to cough) and rash in specifications that include calorie consumption. These latter two symptoms are the next most prevalent symptoms in the data after respiratory and intestinal symptoms. The point estimate for cooking time in the respiratory symptom equation is essentially unaffected by the inclusion of calorie consumption and remains statistically significant.[18] The cooking time 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 is significant and positive, as it is in the intestinal symptoms equation.[19] In the latter equation, cooking time is still, however, not significantly related to intestinal symptoms, net of food intake, consistent with biological models. Indeed in contrast to the estimates excluding calorie consumption, the effect is not even positive. Moreover, the intestinal symptom specification now passes the over-identifying test ($F(5,2502)=0.47$), which evidently has power. The final two columns of the table also indicate that there is no evidence in the data that cooking time affects the incidence of fever or rash, although the low presence of such symptoms makes the power of the test low.

D. Do ventilation and kitchen location matter?

Having assessed the robustness of the instrumental-variables estimation strategy for

[18]The cooking time coefficient from the specification excluding calorie consumption but also excluding persons for whom calorie consumption was not obtained is .349 (t=2.37). This compares with the Table 5 estimate obtained from the same sample but including calorie consumption in the specification of .392.

[19]That body weight, given calorie consumption, rises with increased cooking time, is consistent with the relatively sedentary nature of this activity compared with agricultural work.

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 4, columns (1) and (5), 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 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 7, 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. Contemporaneous intergenerational externalities 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, as our data from Bangladesh show, 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 one and nine years, we estimate the following equation

$$\textbf{(12)} \qquad h_{ijk} = \gamma_0 + \boldsymbol{\gamma}_A \boldsymbol{A}_{ijk} + \gamma_t t_{ij} + \boldsymbol{Z}_j \boldsymbol{\gamma}_z + \boldsymbol{X}_j \boldsymbol{\gamma}_X + \mu_{hj} + \mu_{hij} + e_{hijk},$$

where h_{ijk} is the reported respiratory symptom of a child *k* (age 1-9 years) born to mother *i* in family *j*, the $\boldsymbol{A}_{ijk}$ are the characteristics of the child (age, age squared and gender), t_{ij} is the time allocated to cooking by the child's mother, μ_{hj} is the household fixed effect, μ_{hij} is the mother fixed effect, and e_{hijk} is the error term associated with the child. Given the relationship between child age and proximity to the mother seen in Appendix Figure A, we expect γ_t will be larger for younger children. We thus also estimate (12) for two age groups, 1-4 and 5-9.

The relationship between the mother's cooking time and a young child's health thus can be due to either (a) exposure to smoke associated with being proximate to the mother or (b) a correlation between the mother's endowed healthiness and/or the child's healthiness and the mother's time allocation. Household fixed effects estimation used in estimating previous models only differences out household-specific heterogeneity μ_{hi}. Thus, for example, if mothers are assigned cooking duties based on the illness of their children, such estimates may overstate or understate the effects of cooking time on child health even in the absence of measurement error in *t* depending in part on whether mother's with sick children cook more or less. We again employ our instrumental variables strategy combined with household fixed effects, making use of the mother's household rank variables, which are independent of her children's health status, to predict her cooking time (Bangladesh) and her likelihood of being principal homemaker (India).

For assessing the effects of maternal cooking on children's respiratory health we cannot use the placebo intestinal symptoms to check our results because our previous estimates suggested that food consumption is a significant determinant of such symptoms and is correlated with the mother's time allocation. Although the Bangladesh survey provides information on the individual food consumption of children that may potentially affect their intestinal health, child consumption will be correlated with the error term in (12) - food consumption may be affected by illness. Unlike for mothers, we do not have instruments to predict individual food consumption for children within the family, so we cannot obtain consistent estimates of the determinants of intestinal symptoms for children.[20] Our results suggested that food consumption is not a significant determinant of respiratory illness, at least for adults, so the exclusion of food intake is not likely to bias the estimates of smoke exposure on children's respiratory symptoms.

The Indian survey data do permit a very important robustness check - we can estimate (12) for the control group of households that do not use biomass fuel and/or have clean-burning stoves. For such households the mother's allocation to cooking tasks should have no effect on the respiratory illness of her children. Thus, for the Indian sample we are effectively using a difference-in-difference estimator combined with instrumental variables - differencing across women and fuel/stove type. Because we are estimating (12) across mothers within the household, as long as fuel and stoves are household level choices, the FE-IV estimates obtained on samples stratified by fuel use will not be afflicted by choice-based sampling bias.

Table 8 reports the estimates of exposure effects for children in the Bangladesh sample, all of whom are in housholds cooking with biomass. The first column reports the fixed-effects estimates for the child age group 1-9; the second column displays estimates obtained using FE-IV for the same sample, and the last two columns report the FE-IV estimates for the split age groups 1-4 and 5-9. The household fixed effects estimate of the effect of a mother's time cooking on child respiratory symptoms in column (1) of Table 6 is positive and statistically significant. However, the household fixed effects estimates may be biased, as noted. The estimate of the exposure effect based on the household rank instruments, in the second column, is also statistically significant but is more than twice as large in magnitude than the FE estimate. The FE-IV point estimate suggests that a two-hour increase in the mother's cooking time would double the incidence of respiratory symptoms for children aged 1-9. If the exposure coefficient is picking up proximity to the source of smoke from cooking, we would expect that the effect of a mother's cooking on child respiratory symptoms would be greater for younger children, because

[20]We estimated (12) for intestinal symptoms excluding and including children's calorie consumption. The estimates of exposure effects, available from the authors, were not statistically significant and were also small.

as we have seen they spend more time closer to their mother than do older children.[21] The estimates of columns (3) and (4) are consietnt with a proximity interpretation: the cooking time estimate is almost three times larger for children aged 1-4 than for children aged 5-9. 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 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, who are the youngest children of those who cook.

For the India sample of children, we can carry out the same analysis, except that we can only use the indicator variable for whether a mother's principal activity is household work to measure exposure to cooking smoke. This is a substantially noisier measure of exposure than is cooking time, so we would expect that the within-household estimated exposure effects will be substantially underestimated without using instrumental variables, and precision may be reduced relative to the Bangladesh estimates based on actual time use. As noted, however, we can carry out the analysis separately in households using biomass and in households cooking "cleanly", with either clean fuels or smokeless stoves.

Table 9 provides descriptive statistics for the two sub-samples of households with two or more observations per household, distinguished by whether children potentially experience smoke from cooking fires.[22] As can be seen, while average mother's and children's ages do not differ across the two sub-samples, the incidence of respiratory symptoms is almost 20% higher among children in the biomass-burning households compared with children in the clean-fuel households. This difference is statistically significant (t=3.23). A mother in the former is also less likely to specialize in household work compared with a mother in a clean-fuel household, consistent with the less equitable division of household responsibilities in households where cooking has adverse health effects, discussed in section III. This difference is also statistically significant (t=15.8).

Table 10 reports the first-stage FE-household estimates of the determinants of whether

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[21]We cannot rule out that younger children are also more sensitive contemporaneously to pollution than are older children. We show below that earlier exposure has more lasting effects on respiratory symptoms.

[22]All of the analysis is carried out using household fixed effects.

the mother reports that her principal activity is household work. We again exploit the ranking rules and use five status categories based on the relationship of the woman to the head in the survey year - mother, daughter-in-law, sister-in-law, sister-in-law of the oldest son of the head, and head or head's wife (the left out category). As in the Bangladesh sample, a mother's relationship to the head importantly affects the likelihood she specializes in household work: sisters-in-law and daughters-in-law are more likely to take on such chores compared with the wife of the head, or the head if the head is female. And also consistent with the sociological and anthropological literature, the wife of the oldest son is less likely to be assigned household tasks than the wives of younger sons of the head. The set of rank household variables is highly statistically significant ($F(3, 2802)=28.8$).

Column one in Table 11 reports the within-household estimates of the parameters in (12) for the children in the Indian sample residing in households burning biomass, which replicates the specification used in the Bangladesh sample except that time cooking is replaced by the variable indicating whether the mother's principal activity is home chores. As in the Bangladesh sample (in which all households use biomass) there is a positive association between the mother's exposure to biomass smoke associated with staying in the home and the probability of her children also having respiratory symptoms, although the estimate is imprecise. In column two, the FE-IV estimate of the exposure effect is seven times larger than the effect estimated without instruments, with the FE-IV parameter estimate approaching statistical significance. The point estimate suggests that children aged 1-9 are twice as likely to exhibit respiratory symptoms if their mother's principal activity is homemaker and the household uses biomass for fuel compared with children in the same household whose mother is principally assigned other tasks. Also replicating, though with less precision, the Bangladesh results, the exposure effects are almost completely confined to younger children. In contrast, in regressions (not reported) using the same specifications for the same age groups of children obtained from the sub-sample of households using clean fuels or smokeless stoves there is no statistically significant effect of the mother's allocation to home activities on her children's respiratory symptoms for any age range or estimation procedure, and the point estimates are negative and very small.

The estimates in Table 11 for the Indian households using biomass fuels for cooking replicate the results obtained for the Bangladesh sample, in which all households use biomass, except that there is less precision, while thye estimates from the clean-burning fuel households do not. The two sets of estimates, however, do not indicate whether the difference in the "exposure" effect estimates across biomass-burning and clean-fuel burning Indian households on children's respiratory health are statistically significant, nor whether the differences in maternal activity effects on children's health by child age are statistically significant. To carry out tests of significance, we impose a little more structure and combine the child age- and fuel-specific samples from the Indian data set. In particular, we estimate, using within-household IV, an interactive specification in which the effects of maternal home time on child health can differ by child age and by fuel/stove type.[23]

The first column of Table 12 reports the estimates from a specification in which maternal home time effects differ linearly by child age estimated on the sample of households burning biomass. The coefficients on the linear and age-interaction terms indicate again that a child is more likely to be coughing if he or she has a mother who is a homemaker compared with a child whose mother is not principally working in the home within these households. The effects decline by child's age. The exposure coefficients are jointly significant ($\chi^2(2) = 4.67$) at the .10 level, with the linear exposure coefficient estimated relatively precisely. The point estimates suggest that a child aged two years has 76 percentage-point increased probability of exhibiting respiratory symptoms if he or she has a mother whose principal activity is household work; for a five-year old the increase is 56 percentage points. For both age groups this is approximately a doubling in the probability of respiratory symptoms, as the incidence of such symptoms also declines by age.

In the second column of Table 12, the FE-IV coefficient estimates from the same linear interactive specification are reported for the clean-fuel household sample. The linear effect of maternal home time on child respiratory health is neither positive nor statistically significant and the joint exposure coefficients are also not jointly significant ($\chi^2(2) = 0.27$) . In the final column of the table, all samples are combined and the estimated coefficients from a specification in

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[23]The first-stage equations contain the relevant interactions with the household rank variables. Test statistics ($F(15, 4501)$) for the set of identifying instruments for each of the four endogenous variables used in the merged sample are 8.97 15.7, 11.40 and 71.1. The complete set of parameter estimates are available from the authors.

which the effect of the maternal activity indicator on child respiratory symptoms is allowed to vary both by age and fuel burned are displayed. These estimates again indicate that in homes burning biomass for cooking but not smokeless homes, children with a mother who is assigned to household chores are more likely to have lower respiratory health, particularly younger children. The hypothesis that the joint effects of maternal household specialization on child respiratory health are the same across biomass-using and smokeless homes is rejected at the .06 level ($\chi^2(2) = 5.61$); and the hypothesis that in smokeless homes the mother's activity has no effect on a child's respiratory health is not rejected at conventional levels of significance ($\chi^2(2) = 1.24$).

VI. Longer-term effects of early childhood exposure

Tables 8, 11, and 12 indicate that younger children whose mothers are engaged in cooking or who are principally engaged in home care are significantly more likely than older children to exhibit contemporary respiratory problems in homes using biomass for cooking. This is consistent with our finding that younger children stay close to their mothers while they are cooking and thus close to the pollutant point source when the mother specializes in home care and the household is burning biomass. The question we address in this section is whether early childhood exposure to smoke is also reflected in respiratory problems later in the child's life-cycle. The equation we would like to estimate to identify long-term effects of pollution exposure is:

$$\textbf{(13)} \qquad h_{tij} = \gamma_0 + \Sigma\gamma_{t-n}C_{t-nij} + \Sigma\gamma_{Ft-n}t_{t-nij}F_{t-nj} + \mu_j + \varepsilon_{ijt,} \qquad n=0,...t, t+1,$$

where subscript t=current age of child i for mother j, C_{t-nij}=mother's exposure to indoor pollutants (home care) when the child is aged t-n, where t=-1 is the pre-natal year; μ_j and ε_{ijt} are mother and child fixed effects. In specification (13), the pollutant exposure of the child at any prior age t-n (via the mother's activity C_{t-nij}) may have an age-specific effect on the child's health at the current age t and may differ depending on the household fuel source F_{t-nj}. We wish to know if any of the lagged γ_{t-n}'s are statistically significant.

There are two challenges to estimating (13). First, the mother's pollution exposure (home assignment) may be correlated with her health attributes, which are correlated with the child's health (e.g., a genetic correlation) and/or mothers with sickly children may be more likely assigned home tasks. Differencing across the children eliminates the mother fixed effect (common to all of her children) but still leaves the child fixed effect. This is a problem if mothers may be more or less likely to have spent time at home at every stage of a child's life cycle depending on the specific child's inherent healthiness. To deal with the latter problem we use an instrumental variables approach to predict the mother's activity at every age of the child.

The second challenge is that the India data sets do not provide a retrospective history of maternal activities and thus the activity of any child's mother at every age of the child. However, there is complete retrospective information on household divisions and marriages in the 1999 data back to 1982 along with a history of deaths of any immediate relatives of the 1999 household heads. Thus it is possible to construct a history of the relationship of the mothers in the 1999 survey to the household head back to 1982 and therefore to predict the likelihood of a mother being a primary housekeeper at every age if a woman's within-household status significantly affects her allocation of time, given her age.

Because a mother's status in the household changes due to household division, the marriages or deaths of her brother's-in-law, and/or the death of her husband or the household head, given the hierarchical rules of the division of responsibilities in multi-women households, a woman's exposure to smoke will change over the life-cycle. As a consequence, children of the same mother will also differ in the degree to which they would have been exposed to indoor pollutants at the same life-cycle stage depending on when they were born. Thus, it is possible to identify all age-specific lagged pollution exposure effects using a within-mother estimator. Figure 5 displays the proportion of women in 5-year age groups who are in one of four statuses - wife of head, daughter-in-law of head, mother of head and head based on the construction of the sampled women's relationships to household heads using the marriage, mortality and division, histories. As can be seen, over a woman's life cycle she can expect to change statuses, moving from the low-status daughter-in-law to wife of head or head.

To estimate (13) in the absence of complete maternal task histories we constructed status histories of all of the mothers present in the 1999 survey. More formally, consider the reduced-form determinants of specialization in household care:

(14) $$C_{ijs} = \pi_A A_{ijs} + \pi_s T_{ijs} + \mu_{cj} + e_{ijs},$$

where C_{ijs} indicates whether person i in household j specializes in household care in year s, A_{ijs} is a set of person-specific attributes (relationship to head, age), T_{ijs} is a set of dummy variables indicating year s=1,...,S, μ_{cj} are time-invariant household-level observed and unobserved variables, and e_{ijs} is an iid error term. The missing data problem arises because the household care variable C_{ijs} is only observed at times 1 and S. The explanatory variables A_{ijs} and T_{ijs} are observed, or can be inferred, in every year s=1,...,S and thus can be used to impute values of C_{ijs} for s=2,...,S-1. Central to the validity of this imputation is requirement that the parameter vector (π_A, π_s) is stable over time. Fortunately, both the 1982 and 1999 surveys provide a consistent set of mutually exclusive principal activities, one of which is household care. We can thus estimate (14) the for both of those years. Stability would be indicated by the predicting equation parameter estimates being the same across the surveys, which are separated by 17 years.[24]

Table 13 reports the within-household estimates of the determinants of a married woman's home care specialization in both the 1982 and 1999 and for the combined samples. We use for the $A_{ijs,}$ in addition to age, the same five status categories based on the relationship of the woman to the head in the survey year as was used to obtain the FE-IV estimates of contemporaneous effects of maternal time - mother, daughter-in-law, sister-in-law, sister-in-law of the oldest son of the head, and head or head's wife (the left out category). As can be seen, mothers and sisters of the head are significantly more likely to be homemakers, for given age, compared with female heads or wives of heads and compared with sisters-in-law. Most importantly, the ranking of statuses are similar and the status coefficients statistically identical across survey years - an F-test cannot reject the null hypothesis of the equality of coefficients across survey years ($F(5,6496)=1.26$). Thus we can combine the two samples to obtain a predicting equation for a woman's likelihood of being a homemaker at any age, given her reconstructed status in the household based on the retrospective household and marital histories.

Figure 6 plots the predicted life-cycle proportion of mothers who are principally homemakers based on the column-three combined-sample estimates and the constructed status life-histories (Lowess-smoothed) along with the birth rates by age in the 1999 sample. As can be

[24]It would be interesting to assess how early exposure to air pollution affects adult outcomes such as education and labor supply. To carry out our procedure for adults, however, we would need to rely on retrospective information on exact dates of marriage, births and household exit going back at least 20 years, which is not likely to be accurate.

seen, in rural India women are most likely to be engaged in cooking chores and thus closest on average to the indoor polluting source when they are also most likely to have very young children and when they are old. This life-cycle pattern may be conducive to short-term productivity (as these women are likely to be less productive outside the home in strenuous activities, given own child-care responsibilities when young and decreased vigor when old). However, if there are long-term health effects from young children (and fetuses) being exposed to smoke these hierarchical norms would not be optimal for the longer-term.

Equation (13) is estimated by the method of *multiple imputation* (MI), as summarized in Rubin (2004). The MI estimator consists of randomly drawing J times with replacement from a sample of J households from the combined set of 1999 and 1982 households, as in the standard bootstrap procedure. For each imputed sample m=1,...,M, equation (15) is estimated, and imputed household care $\hat{C}^m_{ijs}$ is calculated as

$$\hat{C}^m_{ijs} = \hat{\pi}^m_A A_{ijs} + \hat{\pi}^m_s T_{ijs} + \hat{\mu}^m_{cj},$$

which is used to obtain a set of η^m's from (14). The point estimates for the parameters vector **γ** are the average of the M imputations $\bar{\gamma} = (1/M)\sum\hat{\gamma}^m$. Denote the variance estimate of the mth imputed data set as $\hat{U}^m$, then the within-imputation variance is the average of the M imputed estimates, $\bar{U} = (1/M)\sum\hat{U}^m$, and the between-imputation variance is $B = (1/(M-1)) \sum(\hat{\gamma}^m - \bar{\gamma})^2$. The variance of $\bar{\gamma}$, the average of the M imputations, is then $T = \bar{U} + (1 + (1/M))B$ and the statistic $(\gamma - \bar{\gamma})T^{1(½)}$ is approximately distributed as a *t*-distribution. Thus the coefficient standard-errors permit appropriate inferences about statistical significance that take into account the use of the auxiliary sample.

The 1999 REDS provides information on health symptoms for children aged less than 10. We estimate (13) for all children aged 5-9 using the MI bootstrap procedure including the predicted maternal exposure (home care) variable for each child's age from conception to birth, the child's first year after birth, the child's second year after birth and at ages 3-4 as well as the child's current age. We include in (13) a household fixed effect and then a mother fixed effect. As controls we also estimate (13) for households burning clean fuel (e.g., liquid gas).

Column one of Table 14 reports the within-household estimates of (13) for the sample of households burning home biofuels using the imputed home care (exposure) variables by child age and the corrected t-statistics. The estimates, which do not make use of the MI procedure, of exposure effects for the pre-natal period and for the first year of life are marginally statistically significant. However, we cannot reject the hypothesis that the two age-specific effects on current health are identical. In column two, estimates of the specification in which the prenatal- and first-year coefficients are assumed to be the same are reported. The exposure effect of the first two years after conception on the incidence of respiratory symptoms at ages 5-9 is statistically significant. Column three reports the MI estimates and corrected *t*-ratios based on the imputation procedure - the *t*-values are smaller as expected, but the two-year post-conception exposure coefficient is still statistically significant. To test whether the early-period exposure effect is spurious, we include in the specification the mothers exposure *prior* to the conception of the child. As expected (column four), the mother's pre-conception activity has no effect on the child's subsequent health; the effects are in evidence only after conception.

Table 15 reports the same sets of specifications for the biomass-burning households but with a mother fixed-effect included. This eliminates any endowment bias without reliance on use of instruments, but exacerbates attenuation bias from measurement error and lowers sample size. The results are similar, but, as expected, somewhat less precise - the effect on current respiratory symptoms of a child's mother being exposed to indoor smoke in the first two years after the child's conception is marginally statistically significant, and not different across the first two post-conception years. However, for the same specifications including either the household or mother fixed effect, there were no statistically or economically significant maternal stove proximity effects at any child age on a child's current respiratory symptoms in the sample of households not burning biomass.[25]

VII. Conclusion

In rural Bangladesh, many 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

[25] These estimates are also available from the authors.

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 respiratory health of women and children, taking into account heterogeneity and optimizing behavior within households. We also investigated whether the effects of exposure to smoke associated with household time allocations were confounded by allocations of food intake.

The results suggest that proximity to stoves adversely affects the respiratory health of women and the young children they supervise both contemporaneously and with a relatively long lag. In particular, children less than five whose mothers specialize in home care are significantly more likely to exhibit respiratory symptoms in households burning biomass in the home compared with households that burn clean fuels, consistent with our finding that younger children are more likley to be at arms' length from their mother whjen she cooks than older children. Moreover, among children aged 5-9, those whose mothers specialized in home care during pregnancy and in the first year after the child's birth were significantly more likely to have respiratory symptoms, given current exposure to indoor pollutants, compared with children whose mothers did not cook during those ages in homes using biofuels and with all children in homes using LPN gas.

The data also indicated that the allocation of tasks among women appears to favor current income at the expense of future income, as households assign women who may be less productive in outside activities to home care. As this includes women in peak childbearing years, this assignment policy, given our findings of long-term effects of early childhood exposure to pollutants, would appear also to increase long-term damage to the lung capacities of the next generation. The observed allocation of activities among poor rural women in biomass-burning areas thus directly constrains economic growth.

Our strategy of using the set of variables describing the rank of the women and mothers in the household to identify both the short- and long-term effects of exposure to cooking emissions, in combination with within-mother estimates and contrasts between households with and without smokeless cooking fuels, also permitted an assessment of whether there are also important effects of food consumption on own respiratory health and direct effects of mother's time on child respiratory symptoms. Our results suggested that these effects are small. These findings thus imply that a strategy of using a randomized stove intervention designed to reduce cooking emissions combined with measurement of individual exposure to particulates to identify the direct effects of particulate exposure on respiratory health is likely to be valid, despite the likelihood that the reductions in emissions will alter the allocation of women's time in the home and increase household income.

Finally, our results suggest that improving ventilation by increasing the permeability of roofs or walls has little effect on respiratory health, consistent with prior studies examining point-source pollutants and health data. The fact that richer households in rural areas seek to make their houses less permeable (by constructing more solid roofs) thus does not necessarily reflect ignorance of the health impacts of IAP or an unwillingness to mitigate its effects.[26] Increasing 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 their children in rural areas than programs that promote behavioral change, given existing choices.

[26]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.

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Figure 1
Proportion of Males and Females with Cough Symptoms in Bangladesh Households, by Age Group

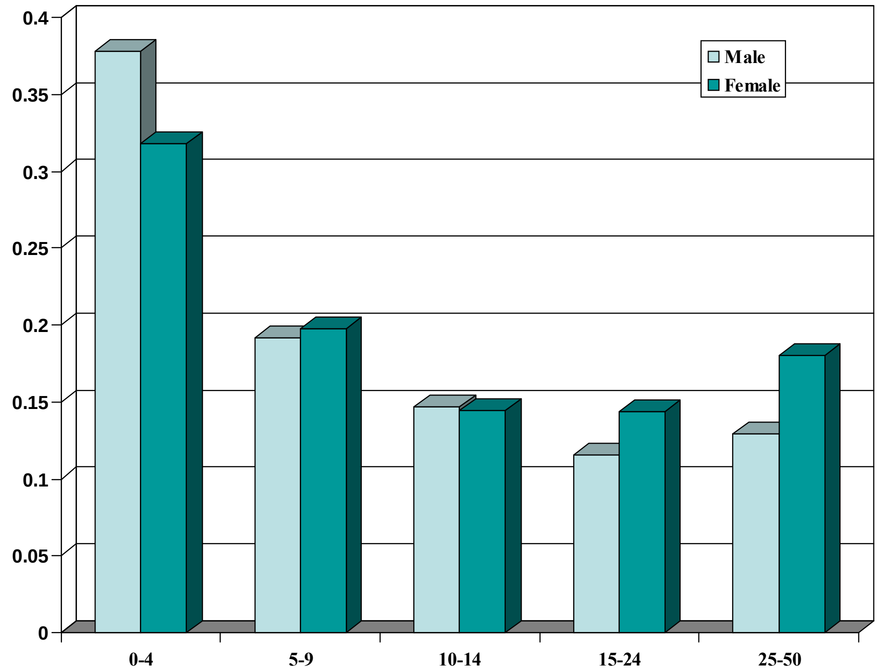


Figure 2
Average Minutes per Day Spent in Cooking Chores in Bangladesh Households, by Age Group and Gender

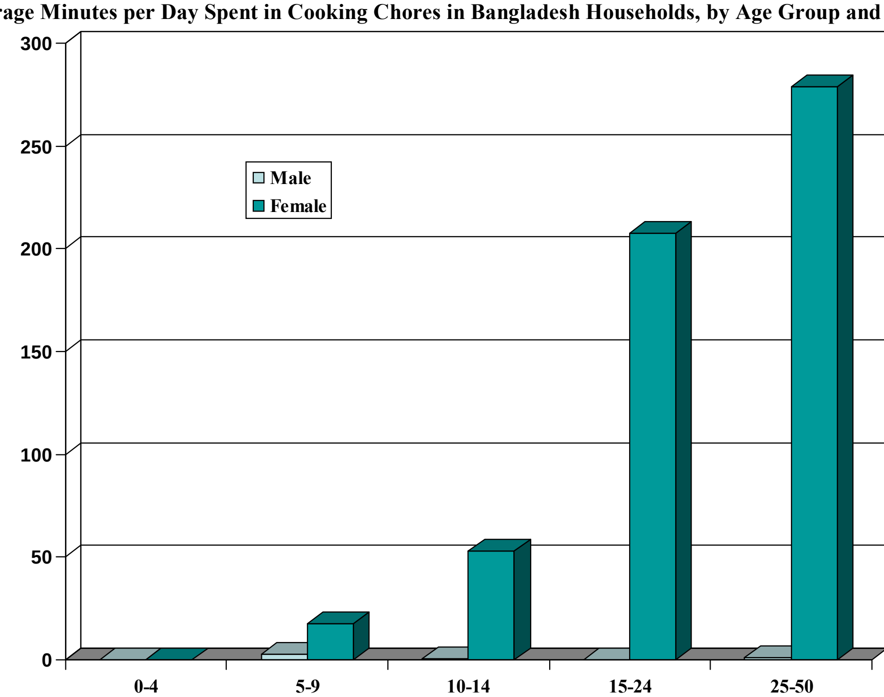


Figure 3
Cooking Specialization in Bangladesh: Distribution of Households by the Share of Total Household Cooking Time of the Woman with the Maximum Cooking Time, by Number of Household Women

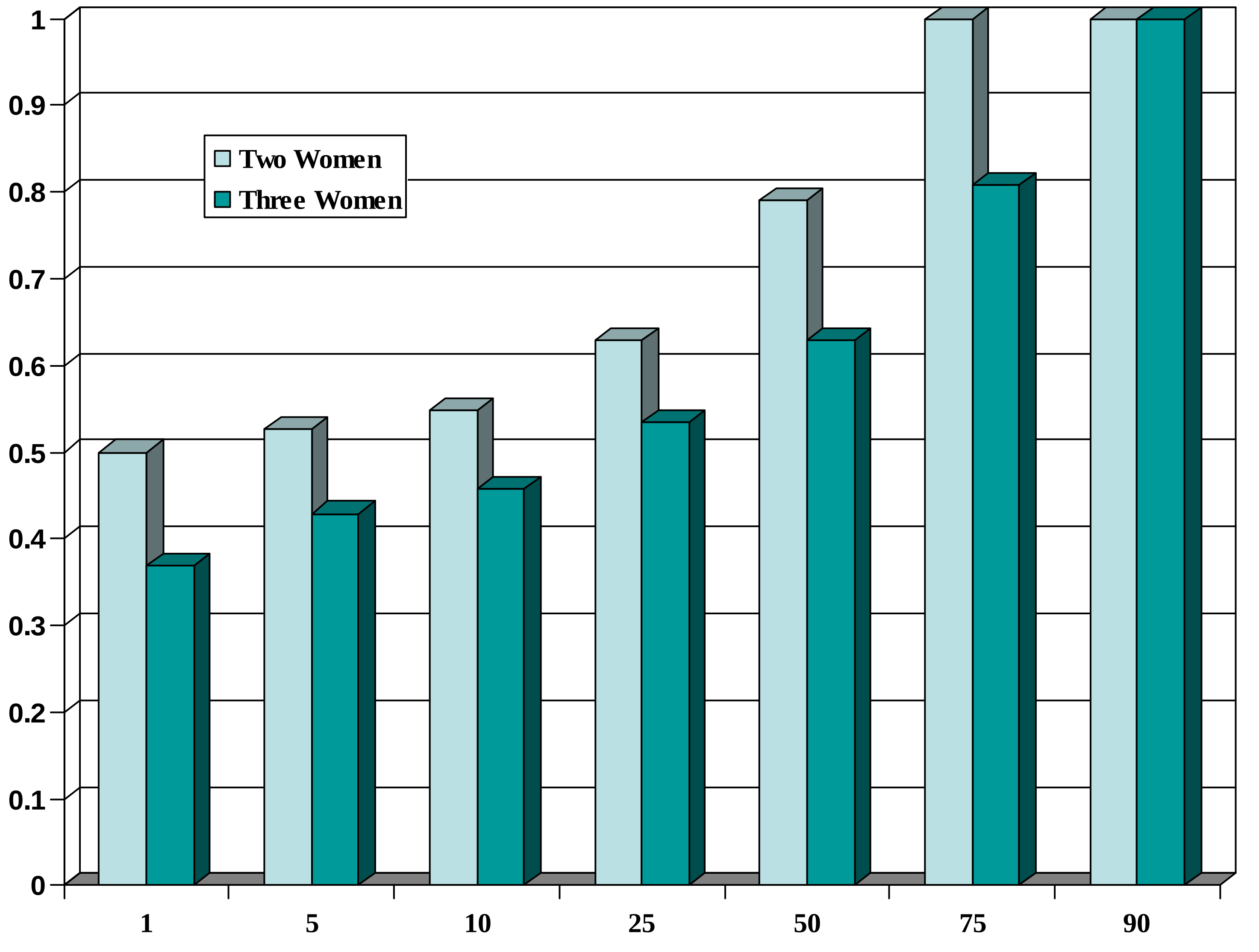


Figure 4
Percentage of Households with Specialization by Women in Rural India, by Fuel/Stove Type and Number of Adult Women

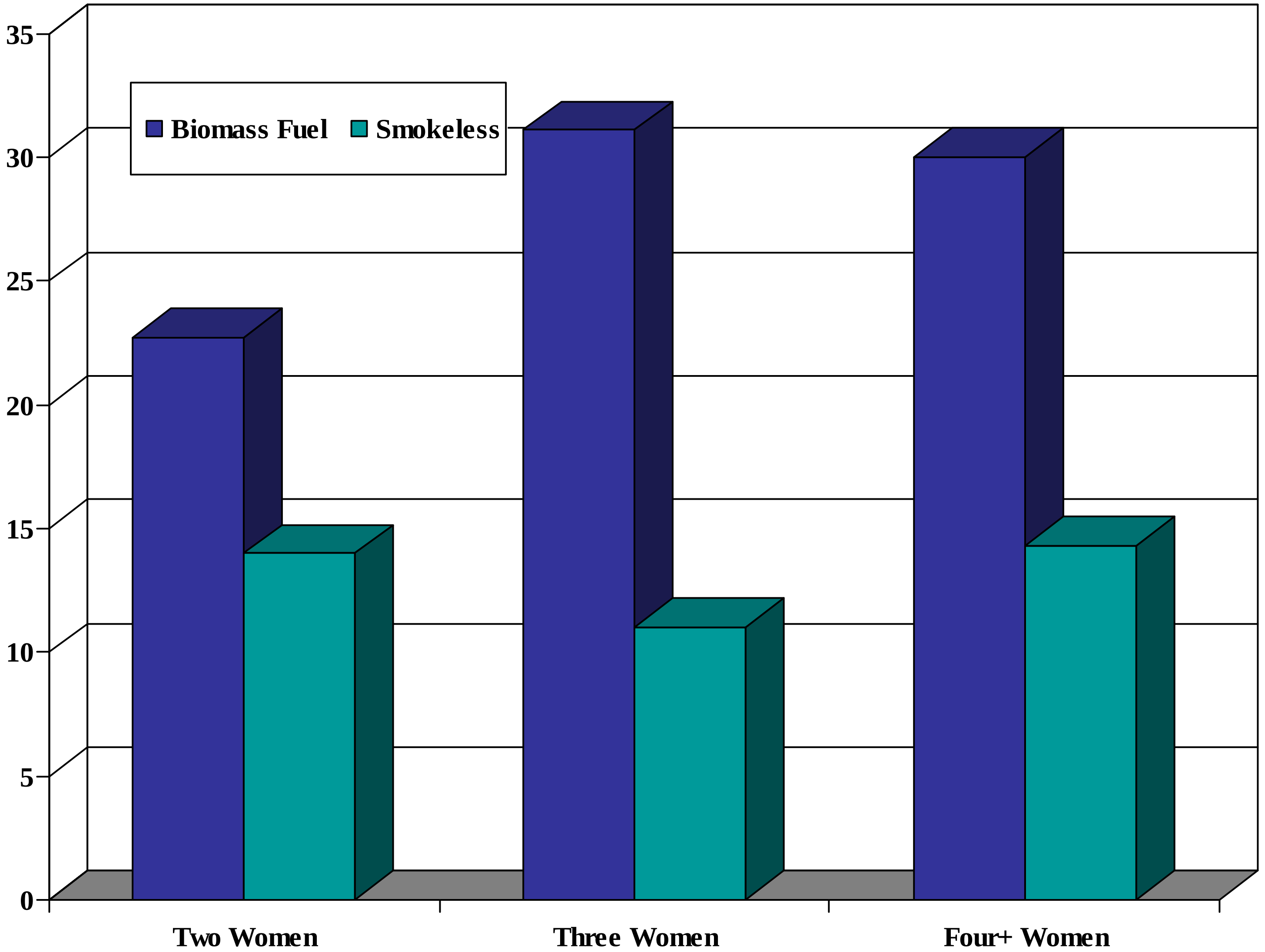


Figure 5
Life-Cycle Status Changes: Proportion of Married Women, by Status Category and Age

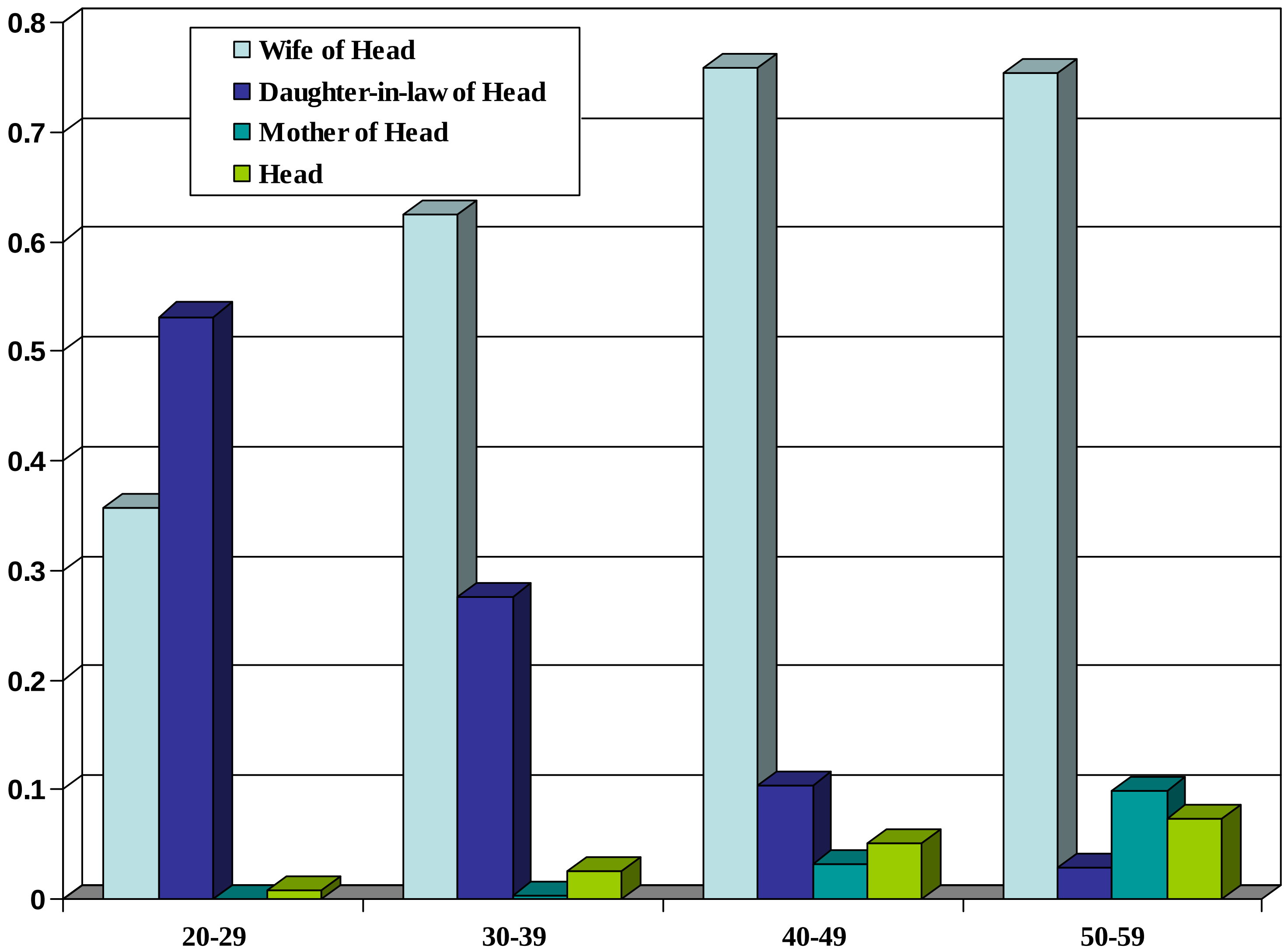


Figure 6: (Lowess-Smoothed) Life-Cycle Probability of Mother Working as a Homemaker And Proportion of Children Born by Mother's Age

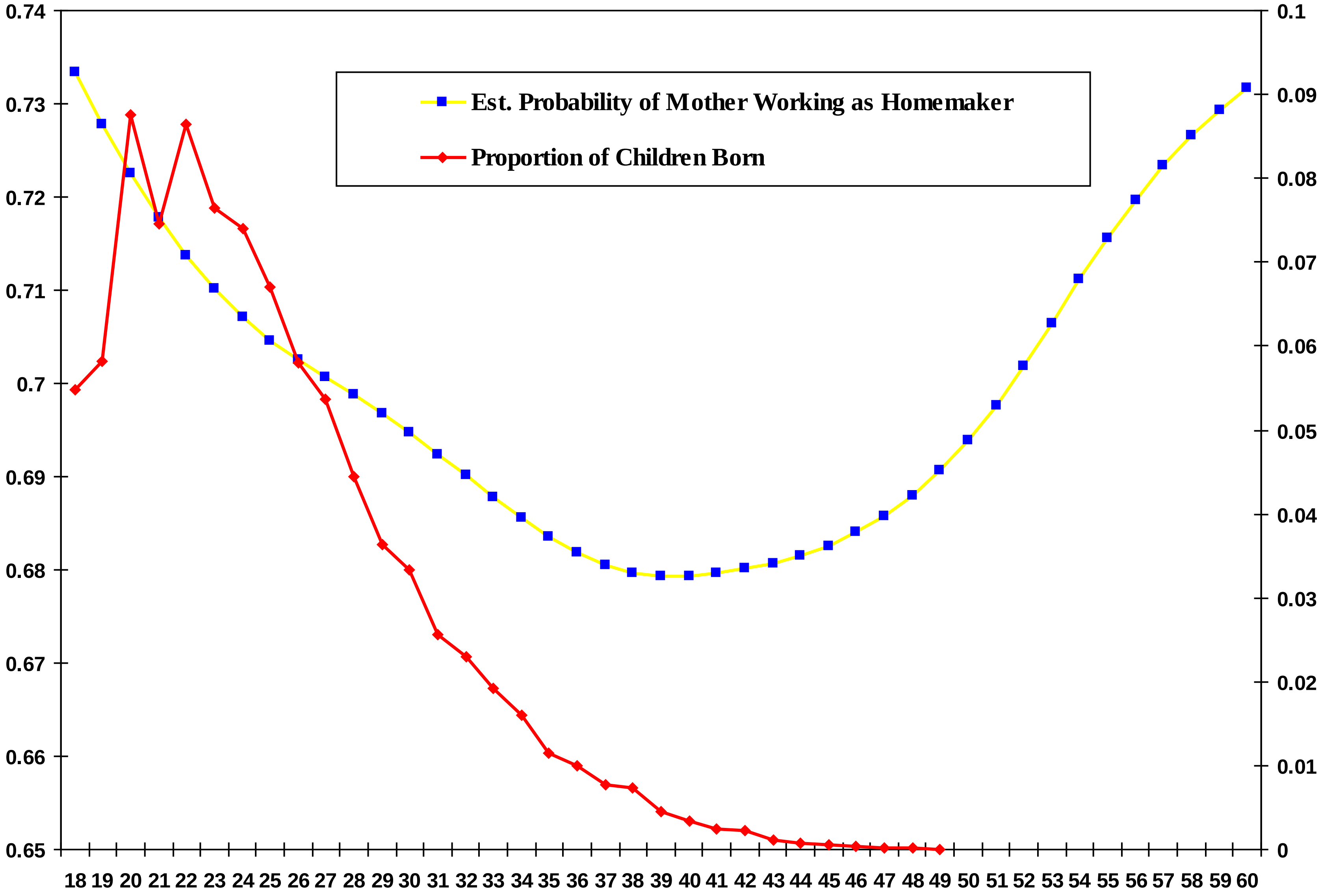


Table 1
Sample Characteristics: 2000-2003 Bangladesh Nutrition Survey

Variable	All Adults Aged 16+	Children 1-9
Respiratory symptoms	.154	.221
	(.361)	(.415)
Intestinal symptoms	.0489	.0694
	(.216)	(.254)
Fever	.0076	.0170
	(.087)	(.129)
Rash	.0092	.0252
	(.095)	(.157)
Age	36.0	6.09
	(15.8)	(1.98)
Education (years)	3.51	.515
	(4.14)	(.939)
Female	.477	.485
	(.500)	(.500)
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

Standard deviations in parentheses.

Table 2
Who Cooks? The Determinants of Cooking Time, All Adults and Women Only, by Estimation Procedure: Bangladesh 2000-2003 Sample

	All Adults Aged 16+		Women Aged 16+	
Estimation procedure	(1) RE	(2) FE-Household	(3) RE	FE-Household
Age	-.557 (6.40)	-.572 (4.85)	-1.54 (6.83)	-2.14 (5.77)
Education	-1.41 (4.18)	-1.98 (3.31)	-4.49 (4.63)	-7.47 (3.88)
Female	143.1 (26.3)	143.7 (30.2)	-	-
Mother with children<5	-12.1 (1.90)	-22.4 (3.64)	-15.6 (2.38)	-54.4 (3.63)
Mother with children<10	27.6 (6.02)	36.9 (8.43)	25.7 (5.45)	59.2 (5.43)
Wife of head	121.3 (15.0)	118.0 (19.6)	118.2 (14.2)	94.3 (7.63)
Daughter-in-law of head	53.3 (4.21)	65.7 (7.63)	46.3 (3.56)	78.8 (3.63)
Wife x number of daughters-in-law in hh	-55.3 (5.61)	-53.6 (7.98)	-50.8 (5.25)	-13.8 (0.81)
Total hh expenditures (x10^{-5})	96.2 (3.12)	-	222.3 (2.86)	-
Permeable roof	5.54 (1.74)	-	10.0 (1.55)	-
Permeable walls	-4.68 (1.73)	-	-9.63 (1.72)	-
Kitchen outdoors	4.04 (1.40)	-	5.26 (0.86)	-
Number of individuals	4026	4590	1919	2202
Number of households	1198	1371	1195	1368

Absolute values of *t*-ratios in parentheses.

Table 3
Who Cooks? Within-Household Determinants of Cooking Time, All Adults and Women Only:
1981-82/2000-2003 Bangladesh Panel Sample with Endowments

	All Adults Aged 16+	Women Aged 16+
Age	-.594	-2.73
	(2.00)	(2.32)
Education	-.532	-5.92
	(0.34)	(0.95)
1982 health endowment	-62.4	-134.3
	(2.84)	(1.83)
Female	167.1	-
	(13.9)	
Mother with children<5	-12.0	62.8
	(0.52)	(0.95)
Mother with children<10	43.2	15.3
	(3.14)	(0.36)
Wife of head	77.5	86.5
	(5.14)	(2.19)
Daughter-in-law of head	38.0	127.2
	(0.75)	(1.12)
Wife x number of daughters-in-law in hh	-25.9	-11.5
	(2.11)	(0.28)
Number of individuals	922	371
Number of households	449	291

Absolute values of *t*-ratios in parentheses. Household fixed-effect included in all specifications.

Table 4
The Effects of Cooking Time on the Incidence of Respiratory and Intestinal Symptoms, All Adults and Women Only, by Estimation Procedure

Sample	All Adults Aged 16+ (Households with 2+ Adults)				Women Aged 16+ (Households with 2+ Adult Women)			
Symptom type	Respiratory			Intestinal	Respiratory			Intestinal
Estimation procedure	RE	FE	FE-IV	FE-IV	RE	FE	FE-IV	FE-IV
Cooking time ($x10^{-3}$)	.152 (2.77)	.0871 (1.56)	.349 (2.72)	.0391 (0.49)	.159 (2.68)	.170 (2.51)	.455 (2.58)	.0852 (0.76)
Age	.00107 (2.84)	.00113 (2.77)	.00146 (3.37)	.000755 (2.80)	.00069 (1.12)	.00178 (2.41)	.00284 (2.96)	.000808 (1.32)
Education	-.00357 (2.09)	-.00106 (0.50)	- .00011 (0.05)	.00108 (0.80)	-.00276 (0.95)	.00465 (1.14)	.00892 (1.87)	.000748 (0.25)
Female	.00093 (0.06)	.0157 (0.92)	-.046 (1.43)	-.00226 (0.11)	-	-	-	-
Total expenditures ($x10^{-5}$)	-.380 (1.88)	-	-	-	-.511 (1.78)	-	-	-
Permeable roof	-.0115 (0.66)	-	-	-	-.0384 (1.59)	-	-	-
Permeable walls	.00225 (0.15)	-	-	-	.0125 (0.59)	-	-	-
Kitchen outdoors	.015 (0.94)	-	-	-	.00948 (0.42)	-	-	-
Number of individuals	4590	4590	4590	4590	2202	2202	2202	2202
Number of households	1371	1371	1371	1371	1368	1368	1368	1368

Absolute values of *t*-ratios in parentheses.

Table 5
FE-Household Estimates: The Determinants of Cooking Time, Calories Consumed and Whether Received Formal Medical Care if Ill

	Cooking Time		Calories		Received Care, if Ill*	
Variable/specification	(1)	(2)	(3)	(4)	(5)	(6)
Age	-1.33	-.792	-.178	.129	.00202	.00170
	(10.2)	(6.73)	(0.20)	(0.14)	(1.59)	(1.31)
Education	-3.43	-2.13	-10.7	-9.18	.00484	.00504
	(4.72)	(3.35)	(2.22)	(1.90)	(0.74)	(0.76)
Female	256.3	160.1	-728.8	-843.6	-.0470	-.0144
	(72.2)	(33.8)	(30.9)	(23.5)	(1.48)	(0.29)
Wife of head	-	144.8	-	129.0	-	-.0594
		(28.0)		(3.28)		(1.13)
Daughter-in-law of head	-	197.6	-	-163.3	-	.0719
		(5.47)		(0.80)		(0.27)
Wife x number of daughters-in-law in the household	-	-67.3 (10.2)	-	104.0 (2.08)	-	.0631 (1.24)
Daughter-in-law x Number of daughters-in-law	-	-19.0 (1.79)	-	10.3 (0.13)	-	.0564 (0.49)
Daughter-in-law x Is there wife of head?	-	-35.4 (1.58)	-	460.3 (2.70)	-	-.295 (1.58)
R^2	.640	.720	.168	.168	.020	.025
F-statistic(p-value))	-	171.5(.00)	-	5.67(.00)	-	1.23(.30)
Number of individuals	3878	3878	3878	3878	1425	1425
Number of households	1371	1371	1371	1371	849	849

*Specification also includes dummy variables for 23 specific symptoms. Sample includes only persons reporting illness symptoms. Absolute values of *t*-ratios in parentheses.

Table 6
FE-IV Estimates: The Effects of Cooking Time and Calories on the Incidence of Respiratory Symptoms, Body Weight and the Incidence of Intestinal Symptoms, Rash and Fever: Adults 16+

Dependent Variable	Respiratory Symptoms	Body Weight (kg)	Intestinal Symptoms	Rash	Fever
Cooking time ($x10^{-3}$)[a]	.392	11.5	-.00296	.00253	.0328
	(2.35)	(3.09)	(0.02)	(0.06)	(0.69)
Calories consumed ($x10^{-3}$)[a]	.00467	7.78	.170	.000188	.000284
	(0.04)	(2.92)	(2.01)	(0.60)	(0.82)
Age	.00156	.0217	.000787	.000019	-.000041
	(3.10)	(1.89)	(2.10)	(0.14)	(0.29)
Education	.00205	.245	.00398	.000289	.000188
	(0.75)	(3.98)	(1.97)	(0.40)	(0.24)
Female	-.0671	-5.22	.128	.0134	-.0268
	(0.57)	(2.07)	(1.50)	(0.43)	(0.79)
Number of individuals	3878	3878	3878	3878	3878
Number of households	1371	1371	1371	1371	1371

[a]Endogenous variable. First-stage estimates given in Table 4, columns 2 and 4. Absolute values of *t*-ratios in parentheses.

Table 7
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, Bangladesh Sample

	(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. Absolute values of *t*-ratios in parentheses.

Table 8
The Effects of Mother's Cooking Time on the Incidence of Respiratory Symptoms of Her Children Aged 1-9, by Estimation Procedure and Age Group (Bangladesh Survey: Households Burning Biomass)

Estimation procedure	FE-Household	FE-IV Household	FE-IV Household	FE-IV Household
Child sample age range (years)	1-9	1-9	1-4	5-9
Mother's cooking time (x10^{-3})	.811	1.75	2.75	.927
	(3.13)	(2.23)	(1.61)	(1.50)
Child age	-.0102	-.00925	-.109	.164
	(0.50)	(0.44)	(0.57)	(1.16)
Child age squared	-.00167	-.0185	.0122	-.0140
	(0.85)	(0.93)	(0.32)	(1.39)
Child female	-.0597	-.586	-.126	-.0213
	(2.24)	(2.18)	(1.48)	(0.56)
Mother's age	.0126	.0132	.0252	.0165
	(2.50)	(2.58)	(1.45)	(1.95)
Number of children	1711	1711	709	1002
Number of households	958	958	599	720

Absolute values of t-statistics in parentheses corrected for clustering at the mother-level.

Table 9
Sample Characteristics: 1999 Indian REDS Households with Two or More Children Aged 1-9, by Fuel/Stove Type

Variable/sample	Households Burning Biomass	Households Using Clean Fuels/Smokeless Stove
Characteristics of the children		
Age (months)	62.4	61.7
	(29.0)	(29.3)
Child is a girl	.469	.460
	(.499)	(.498)
Cough symptoms	.242	.208
	(.428)	(.406)
Characteristics of mothers		
Age (years)	29.5	29.9
	(5.62)	(5.43)
Mother of head	-	.0010
		(.0320)
Sister-in-law of head	.0310	.0269
	(.171)	(.162)
Daughter-in-law of head	.391	.512
	(.488)	(.500)
Oldest son daughter-in-law	.275	.328
	(.447)	(.466)
Principal homemaker	.614	.864
	(.488)	(.343)
Number of children	4420	2638
Number of households	1611	926

Absolute values of *t*-ratios in parentheses.

Table 10
First-Stage Within-Household Estimates of the Determinants of Specialization in Household Care,
(Indian Survey: Households Burning Biomass with Children Aged 1-9)

Variable	
Relationship of woman to head[a]	
Sister-in-law	.188
	(7.43)
Daughter-in-law	.136
	(4.67)
Oldest son daughter-in-law	-.0734
	(5.97)
Age of woman	-.00157
	(1.35)
Age of child	-.000256
	(0.68)
Age of child squared ($x10^{-3}$)	.0001114
	(0.38)
Child is a girl	-.0000926
	(0.02)
Number of children	4420
Number of households	1611

[a]Left out categories: Wife of head and head. No mothers of the head are in this sub-sample.
[b]Test statistic for set of hierarchy instruments, $F(3,2802)=28.8$.
Absolute values of *t*-statistics in parentheses corrected for clustering at the mother-level.

Table 11
The Effects of Mother's Cooking Time on the Incidence of Respiratory Symptoms of Her Children Aged 1-9, by Estimation Procedure and Age Group (India Survey: Households Burning Biomass)

Estimation procedure	FE-Household	FE-IV Household	FE-IV Household	FE-IV Household
Child sample age range (years)	1-9	1-9	1-4	5-9
Mother is principal homemaker	.0720	.575	.684	.0355
	(1.42)	(1.87)	(1.48)	(0.12)
Child age (months)	-.00311	-.00303	.000136	-.00854
	(3.01)	(2.89)	(0.02)	(1.33)
Child age squared ($x10^{-3}$)	.0169	.0168	-.0464	.0457
	(2.08)	(2.03)	(0.50)	(1.19)
Child female	.00337	.00305	.0160	.0171
	(0.24)	(0.21)	(0.53)	(0.82)
Mother's age	.0107	.0217	-.0207	.0446
	(0.57)	(1.07)	(0.63)	(1.28)
Number of children	4420	4420	1848	1848
Number of households	1611	1611	1178	1178

Absolute values of *t*-statistics in parentheses corrected for clustering at the mother-level.

Table 12
FE-IV Estimates of the Effects of Mother's Cooking Time on the Incidence of Respiratory Symptoms of Her Children Aged 1-9, by Household Sample (India Survey)

Household sample	Biomass	Clean Fuel	Combined
Mother is principal homemaker	.897 (2.16)	-.431 (0.48)	-.0633 (0.09)
Mother is principal homemaker x child age (months)	-.00563 (1.51)	.00486 (0.49)	-.00293 (1.06)
Mother is principal homemaker x biomass	-	-	.896 (1.27)
Mother is principal homemaker x biomass x child age (months)	-	-	-.00220 (1.96)
Child age (months)	.000961 (0.34)	-.00597 (0.62)	.000947 (0.35)
Child age squared (x10^{-2})	.00127 (1.43)	.00121 (0.97)	.00105 (1.50)
Child female	.00921 (0.61)	-.0189 (0.96)	-.000250 (0.02)
Mother's age	.0199 (0.96)	.0664 (1.96)	.0326 (1.90)
Number of children	4420	2638	7058
Number of mothers	1611	926	2537

Absolute values of *t*-statistics in parentheses corrected for clustering at the mother-level.

Table 13
Within-Household Estimates of the Determinants of Specialization in Household Care, by Survey Year (Indian Surveys: All Ever-Married Women Aged 15-59)

Variable	1999	1982	Combined[b]
Relationship of woman to head[a]			
Mother	.193	.146	.154
	(5.10)	(1.61)	(4.11)
Sister-in-law	.117	.0610	.105
	(3.83)	(1.60)	(3.74)
Daughter-in-law	.0320	.0235	.0669
	(1.17)	(0.66)	(3.31)
Oldest son daughter-in-law	-.0250	-.0208	-.0307
	(1.53)	(1.06)	(2.01)
Age of woman	-.0197	-.0284	-.0139
	(4.90)	(4.46)	(4.90)
Age or woman squared	.000256	.000394	.000182
	(4.84)	(3.97)	(4.84)
Year of survey	-	-	.0163
			(26.8)
Number of households	6,733	3,948	10,681
Number of women	9,208	5,539	14,747

[a]Left out categories: Wife of head and head
[b]Test statistic for equality of coefficients across survey years, F(5,6496)=1.26.
Absolute values of *t*-ratios in parentheses.

Table 14
Within-Household Estimates of Early Childhood Exposure Effects
on the Health Symptoms of Children Aged 5-9 in Households Using Biofuels (Indian Sample)

Estimation method	FE-HH	FE-HH	FE-HH(MI)[a]	FE-HH(MI)[a]
Maternal exposure - first two years post-conception	-	.154 (3.18)	.163 (2.01)	.181 (1.85)
Maternal exposure - prenatal	.142 (1.31)	-	-	-
Maternal exposure - first year post-birth of child	.170 (1.42)	-	-	-
Maternal exposure - 2nd year post-birth of child	-.0106 (0.91)	-.0992 (0.81)	-.109 (0.71)	-.113 (0.73)
Maternal exposure - child ages 3-5	-.0296 (0.65)	-.0300 (0.66)	-.104 (0.62)	-0.0939 (0.56)
Maternal exposure - pre-conception of child	-	-	-	-.0602 (0.49)
Maternal exposure now	.0193 (0.20)	.0197 (0.82)	.0212 (0.22)	.0219 (0.22)
Maternal age now	.0937 (1.88)	.0938 (1.88)	.0924 (1.86)	.0888 (1.86)
Maternal age squared now	-.00122 (1.83)	-.00122 (1.83)	-.00120 (1.81)	-.00117 (1.82)
Child's age now (months)	.00198 (0.82)	.00197 (0.82)	.00193 (0.79)	.00184 (0.77)
Child's birth order	.0650 (1.11)	.0647 (1.11)	.0647 (1.11)	.0652 (1.11)
Child is girl	.00917 (0.33)	.00916 (0.33)	.00930 (0.34)	.00847 (0.31)
Number of households	1550	1550	1550	1550
Number of mothers	1675	1675	1675	1675
Number of children	2209	2209	2209	2209

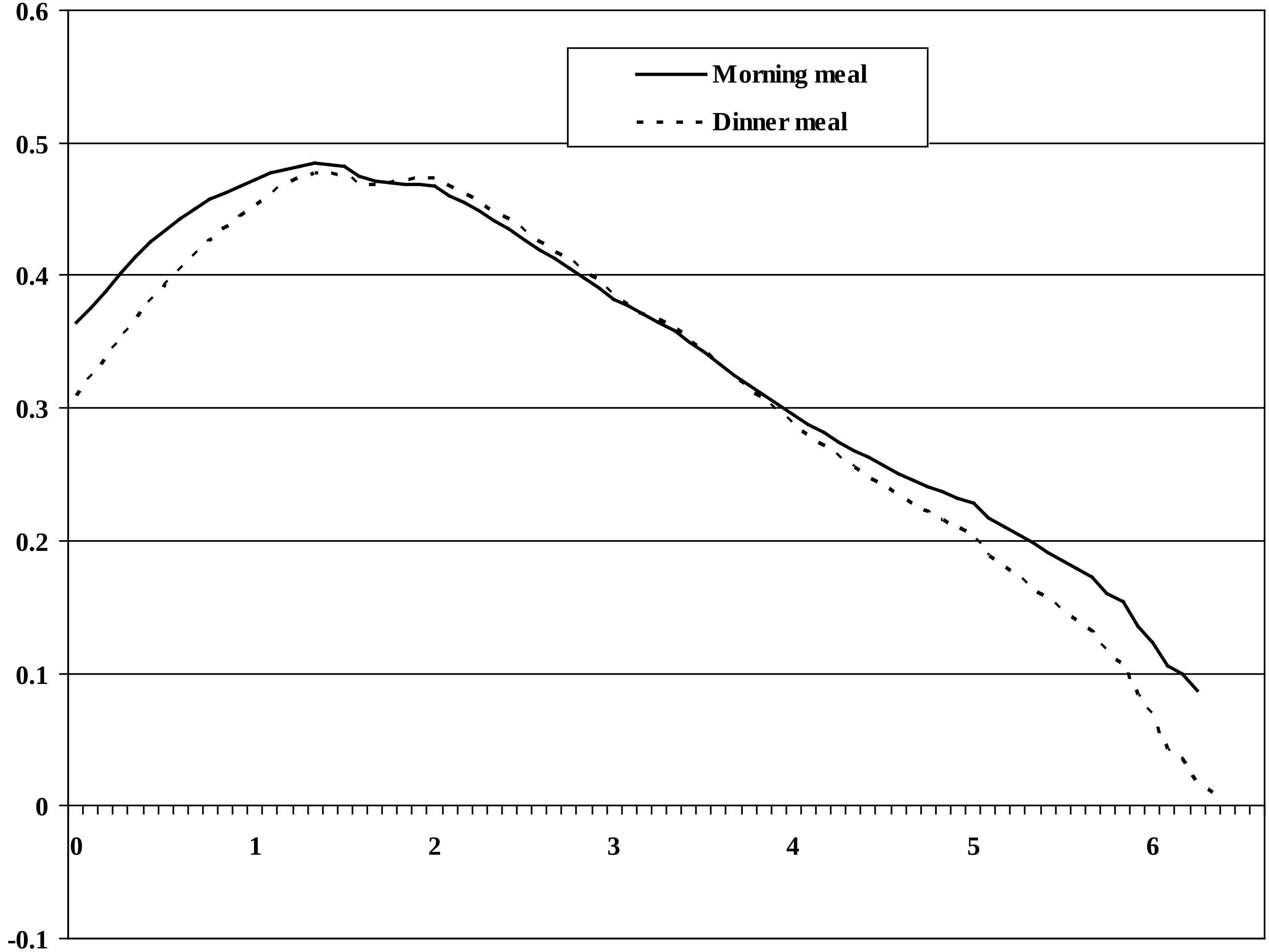
[a] *t*-statistics in column computed according to formula in text.

Table 15
Within-Mother Estimates of Early Childhood Exposure Effects
on the Health Symptoms of Children Aged 5-9 in Households Using Biofuels (Indian Sample)

Estimation method	FE-Mother	FE-Mother	FE-Mother (MI)	FE-Mother (MI)
Maternal exposure - first two years post-conception	-	.135 (2.15)	.141 (1.67)	.160 (1.72)
Maternal exposure - prenatal	.0741 (0.61)	-	-	-
Maternal exposure - first year post-birth of child	.210 (1.54)	-	-	-
Maternal exposure - 2nd year post-birth of child	-.170 (1.33)	-.136 (1.03)	-.160 (0.85)	-.173 (0.92)
Maternal exposure - child ages 3-5	-.0443 (0.72)	-.0470 (0.77)	-.162 (0.71)	-.157 (0.68)
Maternal exposure - pre-conception of child	-	-	-	-.0972 (0.71)
Child's age (months)	.000930 (0.22)	.000799 (0.19)	.000498 (0.11)	.000105 (0.024)
Child's birth order	.0690 (0.82)	.0642 (0.76)	.0652 (1.11)	.0651 (0.76)
Child is girl	.00121 (0.04)	.00036 (0.01)	.00847 (0.31)	.00152 (0.05)
Number of dynasties	1072	1072	1072	1072
Number of households	1550	1550	1550	1550
Number of mothers	1675	1675	1675	1675
Number of children	2209	2209	2209	2209

[a]*t*-statistics in column computed according to formula in text.

Figure A. Fraction of Mothers Who Hold Children "Within Arms Distance" while Cooking, by Age of Child and Time of Meal



Appendix Table A
Sources of Cooking Fuel in Rural Bangladesh, 2007-8

Fuel source	Used Most Often	Second Most Often	Third Most Often
Leaves and straw	37.6	41.8	24.5
Firewood	25.7	22.2	41.7
Agricultural waste	17.4	18.8	15.8
Dung	10.4	9.2	9.9
Gas	4.7	4.6	4.7
Kerosene	0.2	0.3	0.3
Other	3.1	2.3	2.0
NR	0.9	0.9	0.9

Appendix Table B
Logit and Conditional Logit Estimates:
The Effects of the 1982 Health Endowment on the Probability of Death by 2002,
Bangladesh Panel Sub-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

Absolute values of asymptotic *t*-ratios in parentheses.