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Fuel Choice, Indoor Air Pollution, and Children's Health

John H. Y. Edwards
Department of Economics
206 Tilton Hall
Tulane University
New Orleans, LA 70118
edwards@tulane.edu

Christian Langpap
Department of Agricultural and Resource Economics
Oregon State University
Ballard 240 E
Corvallis, O 97331
christian.langpap@oregonstate.edu

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JEL codes: Q53, Q56, D13, I12, O13

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John H. Y. Edwards and Christian Langpap*

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John H. Y. Edwards
Dept. of Economics

Tulane University
Tilton 300
New Orleans, LA 70118
edwards@tulane.edu
(phone) 504.862.8357

Christian Langpap
Dept. of Agricultural &
Resource Economics
Oregon State University
Ballard 240 E
Corvallis, OR 97331
christian.langpap@oregonstate.edu
(phone) 541.737.1473

* Seniority of Authorship is shared.

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Abstract

Much of the world population, particularly in developing countries, still relies on firewood to meet basic energy needs. The resulting indoor air pollution can have severe health consequences, particularly for young children who spend considerable time in close proximity to the fire while their mothers cook. In this paper we use data from a household survey to examine gas stove adoption, firewood consumption, and the resulting effects on the health of young children in Guatemala. Our findings suggest that cooking with firewood has significant negative impacts on children's respiratory health. We also find strong evidence that these impacts go well beyond respiratory problems and have much broader health effects. Simulation results indicate that policies which attempt to reduce the consumption of wood and/or accelerate the adoption of LPG may not be as effective at improving respiratory health as policies that target cooking habits to directly attempt to reduce exposure by young children. However, broader health effects are more effectively addressed by policies aimed directly at eliminating the use of wood fuel.

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1. Introduction

About half of the world population and up to 95% of the population in low income countries still relies on solid fuels, including firewood and other biomass fuels, to meet basic energy needs such as cooking and heating (Smith et al. 2004; Duflo et al. 2008). The overall use of biomass to generate energy is not declining, and it is actually increasing among the poorest households (World Health Organization (WHO) 2002a).

The smoke generated by burning biomass contains particulate matter (PM), carbon monoxide, nitrogen dioxide, sulfur oxides, formaldehyde, and carcinogens such as benzopyrene and benzene. The resulting exposures to indoor air pollution (IAP) are orders of magnitude higher than those recommended by international guidelines and higher than outdoor exposures even in highly polluted areas (Smith et al. 2004). For instance, the U.S. Environmental Protection Agency's standards for average daily concentrations of PM_{10} and $PM_{2.5}$ (particles less than 10 and 2.5 micrometers in diameter) are 150 $\mu g/m^3$ and 35 $\mu g/m^3$, respectively, but typical daily concentrations of PM_{10} in households that use biomass fuels range from 200 to 5,000 $\mu g/m^3$, with peak concentrations as high as 50,000 $\mu g/m^3$ in the immediate vicinity of the fire (Ezzati and Kammen 2002), whereas levels of $PM_{2.5}$ have been measured at over 500 $\mu g/m^3$ (Naeher et al. 2000).

The health consequences of IAP can be severe. Exposure increases the risk of chronic obstructive lung disease in adults and there is growing evidence of links with several other conditions, including tuberculosis, perinatal mortality, low birth weight, asthma, and cataracts. IAP is responsible for approximately two million deaths annually in developing countries and roughly 4% of the burden of disease (in terms of disability adjusted life years) (WHO 2002b). IAP has particularly harmful effects on women who cook and the young children they care for, who are subject to higher exposures because of longer time periods spent indoors and close proximity to the fire. Children living in homes that burn biomass are two to three times more likely to contract acute respiratory infections (ARI) than those living in households that burn cleaner fuels (Barnes et al. 2005). Exposure to IAP increases the risk of acute lower respiratory infections (ALRI), a more dangerous form of ARI that is the leading cause of mortality of children up to five years of age in developing countries (WHO 2002a). The World Bank estimates that 60% of premature deaths caused by local air pollution are children younger than five exposed to IAP from cooking fuels (World Bank 1999).

The link between ambient smoke inhalation and ARI is well established. But though adverse, this is a short-term impact. Long-term health consequences of solid fuel cooking are less well understood. One contribution of this paper is to provide some rare summary evidence and magnitude benchmarks for broader, long-term health effects that persist beyond ARI episodes.

The severity of IAP health effects can be mitigated by targeting the source of emissions (mix of fuels and energy technology), modifying household behavior (avoiding exposure by children or changing the cooking location), or altering the living environment (ventilation and permeability of building materials). The energy ladder model of fuel use suggests that as income increases households will switch from traditional, dirtier fuels such as biomass to modern, cleaner fuels such as gas (LPG) and electricity (WHO 2002b; Barnes et al. 2005). However, households commonly use combinations of fuels, such as firewood and LPG for cooking and kerosene or electricity for lighting. Hence, despite higher prices per unit of usable energy due to inefficient heat generation, the use of biomass can remain high well into the advanced stages of the energy transition.

What explains this prolonged transition to cleaner fuels? First may be ignorance of the health costs borne directly by family members. Lack of information will play a role if households do not fully understand the link between fuel choices, cooking technology, and health (WHO 2002b). Secondly, the adoption of modern fuels may be hindered by the high startup costs involved in acquiring gas or electric stoves. This problem is exacerbated by restricted access to credit, which is common in developing nations (Edwards and Langpap 2005). Poor households may also be unable to purchase fuel in large enough quantities to benefit from lower per unit prices. Finally, cultural factors and related practical limitations of modern fuels and stoves may render them less attractive; for instance, they may be inadequate for preparing traditional dishes.

A number of policies are commonly suggested to speed up the transition to cleaner fuels, modify the mix of fuels used during the transition, and otherwise lessen the negative health effects of cooking with firewood and other biomass. Cost-related obstacles to increased use of clean fuels may be partially overcome by improving access to credit and subsidizing stoves and fuels (Barnes et al. 2005; Edwards and Langpap 2005). Lack of information and behavioral or cultural factors could be addressed by health education campaigns (Ahmed et al. 2005). Finally, higher permeability of construction materials may reduce exposure to IAP (Dasgupta et al. 2004).

In this paper we use data from a household survey to examine LPG stove adoption, firewood consumption, and the resulting effects on the health of children in

Guatemala. We first establish an empirical link between fuel choice, cooking practices, and ARI and then provide strong evidence of broad and chronic impacts through its effect on children's weight-for-age and height-for-age. Although our focus is on the role of fuel choice, we also examine how cooking practices affect health. We investigate the impact of cooking inside, rather than outside the home, the importance of a mother simultaneously cooking and caring for her children, , and the role played by the smoke permeability of housing construction materials.

Previous literature has concentrated on the smoke-ARI link. We use our results to assess the effectiveness of a number of potential policy interventions. We find that policies such as information or health-awareness campaigns to dissuade mothers from cooking when children are present and from cooking inside the home are more effective in reducing the short-term frequency of ARI episodes than policies which target the use of wood or the adoption of gas stoves, such as increased access to credit to finance the purchase of a stove or subsidies for a gas stove or for LPG. We also look at broader health consequences of burning firewood. These results suggest that surprisingly large improvements in anthropometric indicators can be brought about by replacing wood with a cleaner fuel.

2. Background

2.1 Literature

There is a large epidemiological literature on the health effects of IAP (for reviews see Smith et al. 2000; Bruce at al. 2000; or Ezzati and Kammen 2002). However, the economics literature in health and development has not devoted much attention to IAP (see Strauss and Thomas 1998 for a review). Cebu Study Team (1992) estimate diarrhea and respiratory health production functions focusing on identifying individual, household, and community factors that affect these health outcomes. Pitt et al. (2006) examine respiratory health using data from Bangladesh and India, emphasizing the allocation of household responsibilities and the health effects of time spent cooking.

The choice of cooking fuels by households in developing countries and the transition from biomass to cleaner fuels has received more attention in the literature. Amacher et al. (1996) use data from Nepal to estimate household firewood demand and supply functions and examine the use of improved stoves. Heltberg et al. (2000) use data from India to analyze household substitution between forest and non-forest fuels, as well as household response to firewood collection time, common property management institutions, and availability of improved stoves. Pfaff et al. (2004) examine the relationship between income and fuel choice and establish conditions under which a U-shaped relationship between income and IAP may result. Heltberg (2005) uses data from Guatemala to assess the potential of policies that promote inter-fuel substitution. Edwards and Langpap (2005) examine how credit access affects firewood consumption in Guatemala. None of these papers, however, explores the health consequences of fuel choice. This paper contributes to both strands of the literature by focusing on the household's fuel choice and its effects on children's health.

2.2 Fuel Choice, IAP, and Health in Guatemala

The most commonly used cooking fuels in Guatemala are wood and LPG: 74% of all households use wood, and 45% cook with LPG[1]. The use of wood is widespread:

[1] Only 5.4% of households use kerosene, and the use of electricity is limited to the very top of the income distribution (2.5% of households).

practically all households at the bottom of the income distribution use it (99.5% and 98% in the bottom two quintiles), as do most middle-income households (91% and 76% in the third and fourth quintiles) and a third of the wealthier households (34% in the fifth quintile). It is not exclusively a rural phenomenon: although almost all rural households (96%) cook with wood, almost half (46%) of urban households do as well (Heltberg 2005). Most households (55%) combine fuels, using LPG or other clean fuels for quick cooking (such as heating up water) and wood for all other cooking[2] (Ahmed et al. 2005).

The use of firewood remains prevalent despite the general availability and comparable unit cost (adjusted for efficiency in energy generation) of LPG, a cleaner, faster, and arguably more convenient fuel[3]. This may to a large extent reflect the high startup costs of LPG: our estimates indicate that the average price for a stove was 775 Quetzales (about US$ 100) in the year 2000, which represents 46% of monthly household expenditures for households in the lowest quintile of the income distribution, 29% for households in the second quintile, and 20% for the third quintile. Hence, purchasing a stove from current income may not be possible for a majority of households. At the same time, a significant number of households in Guatemala face credit restrictions (36% of households in the 2000 National Living Conditions Survey sample**)**, particularly in the rural sector (44%), which means that financing the acquisition of a stove may not be an option for many households either.

Fuel consumption patterns may also be affected by other household characteristics, including cultural factors that can determine cooking habits, the number, age, employment, and education level of household members, and the geographic or

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[2] However, 42% of households in rural areas use firewood exclusively.
[3] Heltberg (2005) estimates that 75%-81% of the population has access to LPG.

urban/rural location of the family. For instance, wood-baked tortillas, a staple of the indigenous Guatemalan diet, are said to taste differently when prepared with LPG. Additionally, older households may be more traditional, and thus less likely to adopt more "modern" cooking technologies.

The use of wood as a cooking fuel may have a significant negative impact on household health. ARI was the main cause of morbidity and mortality in Guatemala between 1997 and 2000, causing two to three times as many deaths as acute diarrhea, the second main cause of mortality. Furthermore, during this period the number of morbidity cases caused by ARI increased by an average of 31% per year. ALRI, in the form of pneumonia, was the main cause of infant mortality, accounting for 36% of all registered deaths in 2000 (Ahmed et al 2005).

3. Model and Estimation

In this section we present a simple household model of firewood consumption and children's health production[4]. The household derives utility from consumption of a market good, x, a household good such as food, z, produced using energy inputs, and the health of the household's n children, $\boldsymbol{h} = (h_1, \ldots, h_n)$:

$$U = u(x, z, \boldsymbol{h}; \boldsymbol{c}) \tag{1}$$

where $\boldsymbol{c}$ is a vector of household characteristics that are not modeled explicitly but can affect the household's choices. The household good is produced using firewood, w, and a combination of an alternative modern form of energy such as LPG, e, and a stove, s:

$$z = f(w) + g(e, s) \tag{2}$$

where $s \in \{0,1\}$ indicates whether the household owns a stove ($s = 1$) or not ($s = 0$).

[4] Given our empirical focus on children's health, for simplicity we abstract from adult health production.

Health is a function of the amount of firewood used and household characteristics related to cooking habits or the living environment, $\boldsymbol{l}$, such as the location of cooking or whether mothers cook with their children nearby:

$$h_i = h_i(w; \boldsymbol{l}_i) \qquad i = 1, \dots, n. \tag{3}$$

The household's budget constraint is determined by income, y, and the prices of the market good, p_x, firewood, p_w, LPG, p_e, and a stove, $\hat{p}_S$:

$$p_x x + p_w w + p_e e + \hat{p}_S s \leq y \tag{4}$$

where $\hat{p}_S$ reflects the cost of the stove on a per-period basis, including the interest payment when a household has access to credit and can borrow at the commercial rate or the opportunity cost when it does not have access to credit and has to borrow against its own future income at a private interest rate (Edwards and Langpap 2005).

The household chooses the amount of the market good, firewood, modern energy, and whether to purchase a stove to maximize utility (1) subject to the production functions (2) and (3), and the budget constraint (4). From the corresponding first order conditions it is possible to derive demand functions for wood and a stove as well as the corresponding health production functions.

The empirical specifications for the wood and stove demand functions are

$$w_j = \alpha_0 + \alpha_1 s_j + \boldsymbol{\alpha_2 p_j} + \boldsymbol{\alpha_3 c_j} + \varepsilon_j \tag{5}$$

$$s_j = \beta_0 + \beta_1 p_{sj} + \boldsymbol{\beta_2 p_j} + \boldsymbol{\beta_3 d_j} + \mu_j \tag{6}$$

where $j = 1 \dots J$ indexes households, w_j and s_j are household j's observed wood use and stove purchase choices, $\boldsymbol{p}_j$ is a vector of fuel prices, p_{sj} is the price of a stove[5], $\boldsymbol{c}_j$ and $\boldsymbol{d}_j$ are vectors of household characteristics including household consumption, age and

[5] Households may face different prices for fuels and stoves due to regional price differences.

ethnicity of the head of household, number of people living in the home, access to credit, and district where the household is located, and ε_j and μ_j are random error terms.

The empirical specification for the health production functions is

$$h_{ij} = \gamma_0 + \gamma_1 w_j + \boldsymbol{\gamma_2} w_j \boldsymbol{l}_{ij} + \boldsymbol{\gamma_3} \boldsymbol{m}_{ij} + \theta_j + \theta_{ij} + \eta_{ij} \qquad (7)$$

where h_{ij} is the health of the i^{th} child in the j^{th} household. The vector $\boldsymbol{l}_{ij}$ contains variables that enter the model as interaction terms with the wood consumption variable w_j. These include the child's age as well as household characteristics that may directly influence the effect of wood use on health, such as whether the child's mother cooks while she takes care of that child, whether cooking takes place indoors or out, and the permeability of the walls and roof. The vector $\boldsymbol{m}_{ij}$ contains other child- and household-specific characteristics that may influence health, including the child's gender and ethnicity, his or her mother's age, education, and status as household head, household consumption and size, number of rooms in the house, a variable indicating whether the household is rural, and controls for the district where the household is located. The terms θ_j and θ_{ij} capture unobserved household- and individual-specific health heterogeneity, and η_{ij} is a random error term.

We estimate two specifications of the wood consumption model. The variable w_j is first specified as a dichotomous variable that indicates whether the household uses wood to cook. This specification is estimated using a logit model. In the second specification w_j is a continuous variable that measures the quantity of wood used. Since this variable is censored at zero, we use a tobit model for estimation. The stove ownership model (6) is estimated using a logit since s_j is a dichotomous variable that indicates whether the household owns a gas stove or not.

Estimation of the health model in (7) requires that we account for unobserved heterogeneity and potential endogeneity of wood consumption. We address unobserved household-level heterogeneity by estimating household random- and fixed-effects models. To account for the remaining unobserved individual health heterogeneity that may be correlated with other determinants of health, we take an instrumental variables approach and rely on predicted values of wood consumption obtained from model (5) to estimate the health production model[6] (Alderman et al. 2006).

We consider three different health indicators. First, we measure the direct impacts of exposure to IAP. In this case, the health variable h_{ij} is a dichotomous indicator of respiratory infection symptoms for the i^{th} child in household j. Next, we enquire whether exposure to IAP has more wide-ranging health impacts by using more general measures of health. Specifically, the health indicators h_{ij} are continuous variables that measure a child's weight-for-age (WAM) and height-for-age (HAM) (Thomas et al. 1990; Pitt et al. 2003; Alderman et al. 2006). WAM and HAM measure weight and height as percentages of the median weight and height from a random sample of healthy infants and children. The measures were developed by the U.S. National Center for Health Statistics and are widely used by the WHO, World Bank, and others (see Cogill 2003). ,

We start by estimating a household random-effects logit model for ARI with instrumented values for wood consumption. This approach allows for unobserved household-level health heterogeneity, but assumes that the household-specific effects are uncorrelated with the explanatory variables. Incorporating unobserved heterogeneous effects that may be correlated with the explanatory variables requires using a household

[6] This approach relies on stove ownership as an instrument for wood use. Ownership of a gas stove is correlated with wood consumption, but has no direct effect on health.

fixed-effects procedure. This raises two additional issues in our case. First, a fixed-effects procedure differences out all household-level variables along with the household-specific effect, including wood consumption, our focus variable, and the interaction terms with cooking location and permeability. We can only identify the effects of the interaction terms between wood consumption and a child's age and between wood consumption and a variable that indicates whether the mother cooks while she is taking care of a particular child (since these are child-specific variables). Second, we are unable to estimate a fixed-effects (conditional) logit because there are too many households where either all the children or none of the children have had a respiratory infection ($h_{ij} = 1$ or $h_{ij} = 0$ for all i in j). Instead, we estimate a fixed-effects linear probability model[7].

Estimates of the more general health effects (the anthropometric models) are obtained by regressing (the log of) WAM and HAM on the same set of individual child and household characteristics, including instrumented values for wood consumption. We estimate household random- and fixed-effects specifications.

We estimate two versions of each of these models, using predicted values for both the probability that the household uses wood and the quantity of wood used. We adjust the asymptotic variance-covariance estimates to allow for the first-stage errors by bootstrapping (Cameron and Trivedi 2005).

4. Data

The data we use to estimate models (5)-(7) comes from a household survey, the ENCOVI 2000-*Encuesta Nacional de Condiciones de Vida* (Living Standards Measurement

[7] A potential problem with this approach is that the predicted probabilities may be negative or larger than one. In our case this is not an issue: practically all predicted probabilities (at least 98.7%) lie in the [0,1] interval.

Survey), which gathered information on a wide range of topics, including demographic characteristics, health, education, expenditures, savings, and fuel use. The survey was conducted in Guatemala in the year 2000 by the Guatemalan National Institute for Statistics (INE, *Instituto Nacional de Estadística*) with funding and technical support from the World Bank. This is a stratified, random, national survey with rural and urban strata as well as six ethnic strata[8]. Information is available for a total of 7,276 households, of which we select the 5,816 that have children.

The dependent variables in our empirical models measure a household's wood consumption, stove ownership, children's respiratory health, and weight-for-age and height-for-age expressed as percentages of the healthy reference population median values (WAM and HAM). Wood consumption is measured first by a dichotomous variable that indicates whether the household used wood in the month preceding the survey, and then as the logarithm of the quantity of wood used by the household in the previous month[9]. Stove ownership is represented by a dummy variable set equal to one if the household owns a gas stove and to zero otherwise. Children's respiratory health is measured by a dummy variable set equal to one if the child experienced symptoms of a respiratory infection, such as coughing, fever, or trouble breathing, in the month preceding the survey, and set equal to zero otherwise. WAM and HAM are continuous variables that measure a child's weight and height standardized by age.

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[8] Documentation on the survey and information about access to the data can be found online at http://www.worldbank.org/lsms/country/guat/gt00docs.html.

[9] Seasonal variation in wood consumption is not a major concern because in Guatemala's tropical climate temperature variation is mostly due to altitude rather than time of year. Furthermore, 98% of wood-consuming households reported using it exclusively for cooking, so consumption should be fairly constant throughout the year.

WAM and HAM were collected for all household members. Since our focus is child health, we confine our attention to the 0 to 15 age range to ensure that observed health outcomes are more likely to be influenced by the home and not a work environment. Information on respiratory infection, however, was gathered only for children 5 years of age and younger. The data in the first subsample for estimation therefore only includes children under the age of 6 with non-missing, correctly coded data. Finally, in order to compare WAM and HAM results to ARI estimates, we also re-estimate the anthropometric indicator models for the younger sub-sample.

The vector of fuel prices includes the natural logarithm of the prices of wood, LPG, electricity, coal, and kerosene. All fuel price variables are unit costs obtained by dividing the reported value of a household's expenditure on a fuel by the quantity of the fuel consumed. For households that do not report expenditures on a fuel we used the average unit cost for the county ("*municipio*") where they reside.. The price of a stove is proxied by each household's estimated current market value of their stove. When households did not own a stove, we used the average estimated market value for all households that had acquired a stove during the previous year.

To measure access to credit we use a section of the survey that asked households whether they had received or applied for a loan in the preceding year. If the answer was no, the household was asked about the main reason for not applying. We define a household as not having access to credit if the respondent reported not having applied for a loan because no loans were offered in the community, because he or she did not know how to apply for a loan, did not have enough income or assets to offer as collateral, or reported that loans were "not given to people like them". We define a household as having access to credit if it had outstanding loans, it had applied for a loan (even if the loan was rejected), or chose not to apply for a loan because of fear of losing the collateral, high interest rate, preference to use its own resources, lack of investment opportunities, or no need to borrow.

In the health production functions, the wood-use dummy or the wood quantity consumption variables are interacted with the child's age and with four household characteristics: whether the child's mother cooks while she is looking after children, whether cooking takes place inside or outside, and the permeability of the home's walls and roof. We rely on the time-allocation section of the survey to create a dummy variable that identifies women who cooked while they were taking care of children, and link mothers to their children through an identification code created as part of the survey. Households were also asked where cooking usually takes place. We use this information to construct a variable that indicates whether cooking takes place inside or outside of the home. Finally, households were asked about the predominant material in the walls and the roof of their home. We use this information to construct indicators for permeability. The walls are considered permeable if they are made of metal sheets, wattle and daub, or cane and sticks. The roof is considered permeable if it is made of metal sheets, shingles, palm leaves, or similar materials.

We control for additional characteristics of a child's mother by including her age, a dummy variable set equal to one if the mother has no education, and a dummy variable set equal to one if the mother is the head of the household. We also control for household income by including the logarithm of total reported consumption expenditures in the month preceding the survey. Finally, other control variables are the size of the household, measured by the number of people living in the home, the logarithm of the age of the head of the household (in the wood use models only), the number of rooms in the house, a variable that identifies whether the household is located in a rural or urban area, and dummy variables describing ethnicity and the district where the household is located. Descriptions and summary statistics are provided in Table 1.

5. Results

In this section, we present and discuss the estimation results for our econometric models. We first focus on wood use and stove ownership and then on children's health. In addition to discussing relevant coefficients and their statistical significance, we interpret the marginal effects in context[10].

5.1 Wood Use and Stove Ownership

The results for the stove ownership and wood use models are presented in Table 2. Heteroskedastic-robust standard errors appear in parentheses below the estimated coefficients.

The first column of Table 2 presents the estimated coefficients for the gas stove ownership model[11]. We find that access to credit and the prices of a stove and of LPG have statistically significant effects on the probability of stove ownership; the estimated coefficients for these variables are all significant at the 1% confidence level. Marginal effects suggest that, while the effect of access to credit is also economically meaningful, the effects of changes in prices are relatively small. Specifically, whereas providing

[10] Marginal effects are evaluated at the sample means.
[11] A stove ownership model that included additional household characteristics and ethnicity and district dummies was estimated as well, but these variables are not significant so we opted for the more parsimonious model. The results are the same.

access to credit would increase the probability of stove ownership by 15%, a 1% decrease in the price of a stove increases the probability of stove ownership by 0.6% and a 1% drop in the price of LPG increases it by 0.2%. We also find that higher wood prices and lower electricity prices increase the probability of stove ownership. Finally, the coefficient for consumption suggests that gas stoves are normal goods.

The second and third columns in Table 2 present the estimated coefficients for the wood use and wood consumption models. The coefficient for stove ownership is negative and statistically significant, suggesting that if households own a gas stove they are less likely to use wood at all, or if they do they use smaller quantities of wood. Specifically, the marginal effects indicate that owning a stove decreases the probability that a household uses wood by 9% or lowers monthly wood consumption by 79%. Other relevant variables have the expected effects: the price of wood has a negative and significant coefficient, as does the level of total household consumption, suggesting that wood is an inferior good. Older households are more likely to use wood, possibly because they are more traditional and hence less willing to transition to LPG, or because the fact that they are older means they will have fewer years to reap the returns from investing in a gas stove. Finally, larger households require more energy and hence use more wood.

5.2 Respiratory Health

Table 3 shows the estimated coefficients and standard errors for the respiratory health production functions. We estimate two versions of the model, one for a wood use indicator and another that employs the continuous measure of wood consumption. For each of these we estimate two alternative specifications: a random-effects (RE) logit and a fixed-effects (FE) linear probability model[12]. All models use instrumented (IV) values for wood use or wood consumption obtained from the models discussed in the previous section. All standard errors are obtained by bootstrapping to account for the use of predicted values in estimation.

A likelihood ratio test rejects the hypotheses that the wood use or the wood consumption variables are jointly insignificant in the RE models[13]. The estimated coefficients for wood use and wood consumption in the RE models are not statistically significant on their own, but the coefficients of the interactions with the mother cooking and caring for children and cooking inside the home dummies are positive and significant. This suggests that it is not so much the use of wood in a household *per se* that affects children's respiratory health, but rather its use in conditions that intensify exposure. The marginal effects support this interpretation: conditional on a household using wood (or on the mean quantity of wood consumption), if cooking takes place within the house young children in the household are 9% to 12% more likely to have an upper respiratory infection within the last week. If a mother cooks while she is caring for her children, then those children are an additional 12% - 14% more likely to report symptoms of respiratory infection. The estimates of the relevant coefficient in the FE linear probability models are consistent with these results, but they are only significant in the model with the wood-use dummy variable.

The coefficient of the interaction term with age is not significant, suggesting that the respiratory health effects of IAP exposure do not significantly change with age for children 0-5 years old. The coefficients of the interaction terms with the roof and wall

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[12] We also estimated logit models without random or fixed effects, and the results are consistent with those presented in Table 3.
[13] $\chi^2(6)$=23.7 and $\chi^2(6)$=16.3, respectively.

permeability indicators have the expected negative sign, but they are not statistically significant. This suggests that, after controlling for other relevant exposure factors, permeability of construction materials does not play an important role in children's respiratory health. One possible explanation for this result, suggested by the summary statistics in Table 1, is that there may not be enough variation in permeability in our sample (most homes have permeable roofs and non-permeable walls) for it to be a relevant factor.

5.3 Anthropometric Health Measures

Tables 4-7 show parameter estimates and standard errors for models based on anthropometric measures of children's health. We report results for all children ages 0 to 15 years of age. We also separately report results for the 0 to 5 age subsample, in order to facilitate comparison with the ARI estimation results. Tables 4 and 5 show estimation results for weight-for-age,while tables 6 and 7 show results for height-for-age. As we did for respiratory health, we estimate random- and fixed-effects specifications for models with instrumented wood use and wood consumption[14].

We find significant evidence that the use of wood has wide-ranging negative effects on children's health that extend beyond specific symptoms of respiratory problems to more general measures of health and which, furthermore, reach beyond the early childhood years. The coefficients for the wood use/consumption and age interaction terms are negative and significant in all but three of the models. Additionally, the coefficients of the interactions with indicators for cooking inside the home and cooking and caring for children are negative and significant in the RE models. This suggests that

[14] OLS versions of each model were estimated as well. The results are consistent with those presented in Tables 4-7.

the use of wood, or larger quantities of wood, has a negative effect on children's WAM and HAM measures, and that this effect worsens as children grow.

Other estimated coefficients that are consistently significant across most of the RE models have the expected effects. Children from households with higher consumption and homes with more rooms, both variables that are positively correlated with household income, have higher WAM and HAM. Children from larger, rural households where the mother has no education have lower WAM and HAM.

5.4 Robustness

We check the robustness of our results by estimating alternative specifications of our models. First, the results discussed above for wood use (or consumption) and stove ownership are based on estimating the two models separately. However, it is possible that stove ownership is endogenous in the wood use and consumption models. Hence, we consider two additional specifications. In the first one, models (5) and (6) are estimated together using full-information maximum likelihood. In the second one, we use access to credit as an instrument for stove ownership[15], obtain predicted probabilities for stove ownership from model (6), and use them to estimate model (5). The results are consistent with those discussed above.

Additionally, we estimated the WAM and HAM models using variables that measure the length of time a child was breastfed and weight-for-height for the child's mother. The results are consistent with those reported here.[16]

[15] Access to credit is an adequate instrument since it is highly correlated with stove ownership but not directly with wood use.

[16] These variables were left out of the final version of the model because the mother's weight-for-height is not statistically significant and time-breastfed is likely measured with error and it also forces us to drop a significant number of observations.

6. **Policy Simulations**

Our results have several very interesting, practical implications. We begin by examining ARI in small children and then go on to look at what appear to be the broader health implications of firewood use.

If policies are narrowly aimed at reducing the health consequences of IAP then accelerating the adoption of a gas stove or otherwise seeking to reduce wood consumption may not be as effective as reducing smoke exposure by changing cooking behavior. In contrast, simulations of impact on weight and height for age suggest that eliminating the use of firewood could dramatically increase measured overall health.

6.1 Acute Respiratory Infection

We begin by using our empirical results to examine the effects of policies commonly proposed to mitigate the effects of cooking with wood on ARI. We consider the effects of attempts to reduce wood consumption by promoting the adoption of gas stoves and contrast these outcomes with policies that focus on changing cooking practices so as to reduce the smoke exposure of young children.

Adoption of a gas stove will reduce the amount of wood used. This can be encouraged by improving access to credit, subsidizing gas stoves, or directly subsidizing LPG (Ahmed et al. 2005; Barnes et al. 2005; Duflo et al. 2008). However, our estimation results suggest that, for a given level of wood consumption, IAP exposure can be reduced more effectively by not cooking inside the home and by discouraging child care givers from cooking with children present. In Guatemala there is a “dire shortage of information” about health effects of IAP, and women are frequently not aware of the link between IAP and health (Ahmed et al. 2005; WHO 2002). Hence, changes in cooking practices could be achieved through outreach and health awareness campaigns.

The results of policy simulations conducted using our estimates confirm these conclusions. We use the results in Table 2 to obtain predicted probabilities of stove ownership and predicted wood consumption and the estimates in Table 3 to obtain predicted probabilities of ARI. We use sample weights to project predicted sample effects to corresponding national amounts. We simulate the impact of granting universal access to credit for buying a stove, of price subsidies for gas stoves and LPG, and of a health awareness campaign that induces a change in cooking location to outside of the home or induces mothers to avoid cooking while children are under their care.

Simulation results indicate that improved access to credit and stove or LPG subsidies would increase stove ownership and reduce wood consumption, but would make practically no difference in the number of ARI cases[17]. For instance, universal access to credit would increase stove ownership by 4% and in turn decrease wood consumption by 3%, but this translates into a reduction of less than 0.1% in the number of ARI cases. A 50% stove subsidy would increase stove ownership by 38% and decrease consumption of wood by almost 20%, but would reduce the number of children with ARI by only 0.6%. Similarly, a 50% subsidy of LPG would increase stove ownership by 11% and reduce wood consumption by 6%, but reduce ARI cases by only 0.2%.

A health awareness campaign that modifies cooking behavior could have a larger positive impact on respiratory health[18]. A campaign that changes the location of cooking

[17] Complete simulation results and methodology description are not included due to space considerations. They are available upon request.
[18] We assume that such a campaign would not affect stove adoption or wood consumption, but instead would directly reduce exposure.

to outside of the home in 50% of households would reduce the number of ARI cases by about 1%. A campaign that reduces the number of women who cook with children present could have a considerably bigger impact. Even if it only induces a behavior change in 10% of its target population, it would be more effective than universal access to credit or 50% subsidies for stoves or LPG. A campaign that is 50% effective could decrease the number of children with ARI by close to 4%, more than five times the largest impact attainable with a subsidy, and at 100% effectiveness the number of ARI cases would decrease by almost 7%.

6.2 Overall Health Effects

What role does using wood as the primary fuel have on broader health measures? To get an idea of the magnitude of the effect we perform a simple thought experiment. We use the FE models to calculate fitted values for WAM and HAM with sample values for all variables. Then we generate predicted values with the wood use dummy variable or wood-use quantity variables set equal to zero and calculate the change in predicted anthropometric measures. In addition to WAM and HAM, we calculate average weight-for-age and height-for-age z-scores (WAZ and HAZ) and measure severe malnourishment and stunting.[19] The results summarized in Table 8 are remarkable.

The simulation for WAM suggest that if households stopped cooking with wood, the average child's weight-for-age would climb by 8% to 9% of the reference median (9% to 11% in relation to observed values) in the weight-for-age distribution for children 0 to 15 and by 6% to 16% of the median (7% to 18% relative to observed values) for the

[19] The standard score or "z-score" are normalized measures that express weight and height as $z=(x_i-\mu)/\sigma$, where x_i is the weight (height) of child "i" and μ and σ are the mean and standard deviation, respectively, drawn from the weight (height) distribution of an international reference sample of healthy children.

younger sub-sample. The lower and upper bounds of these ranges are defined by whether the wood-quantity or wood-dummy specification is used in the simulation.[20]

These results are certainly significant in their own right, but this change translates into a dramatic rise in z-scores: 58% to 66% for the full sample and 49% to 129% for the younger children. Interestingly, the dichotomous definition of malnourishment[21] and the density of the sample distribution in the neighborhood of the severe malnourishment cutoff signify that measured severe malnourishment would fall by 65% to 87%.

The effects on HAM, are also very significant, though less dramatic. Depending on whether the model includes wood quantity or the wood-use dummy, the height for age measure rises by 0.4% to 1.4% for ages 0 to 15 and by 1.3% to 3.5% for the younger group. These effects seem small in comparison. But again, the distribution of the simulated impact means that increases in height-for-age z-scores would range between 5.5% and 18% or 17.3% and 47.1% for the two groups, respectively. Finally, the density of the sample height-for-age z-score distribution in the neighborhood of the (z = -2) cut-off means that measured severe stunting would fall 7.7% to 25.9% or 22.6% to 54.4%.

7. Summary and Conclusions

Indoor Air Pollution caused by firewood has significant health consequences in the developing world, particularly for young children who suffer high rates of exposure when their mothers cook while caring for them. Research to date has focused on acute

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[20] The estimations and simulation were repeated directly predicting weight and height with similar results. Also, substituting the frequently used 1990 U.K. reference growth charts (see Cole, et al., 1998) *increased* measured severe undernourished and stunting but did not substantially alter the magnitude of simulated impact of firewood use.

[21] The international measure for severe child malnutrition is a z-score of more than 2 standard deviations below the international standard (z < -2).

respiratory infections. Several policy options have been proposed to mitigate this effect of IAP, including policies that attempt to speed the transition to cleaner fuels such as LPG and policies aimed at reducing exposure rates by modifying cooking behavior. In this paper, we estimate econometric models to examine gas stove ownership and wood consumption decisions and to identify the major factors determining children's respiratory health in Guatemalan households.

Our results suggest that access to credit, the price of LPG, and the cost of gas stoves play a key role in determining whether households own a stove. They also indicate that stove ownership and the prices of wood, LPG, and other fuels affect households' wood consumption choices. The effects of wood consumption on ARI, however, are conditional on factors that determine exposure. Specifically, the amount of wood consumed, as such, does not have as significant an effect as when it is conditioned on the location of cooking and on a mother simultaneously cooking and caring for children.

If we ignore other possible health consequences of burning firewood and the policy focus is exclusively on reducing childhood ARI our results suggest that policies that improve access to credit or subsidize the price of stoves or LPG are likely to be effective in increasing stove ownership and decreasing wood consumption in Guatemala, but that these policies would have very small effects on children's respiratory health. Policies which focus on modifying cooking behavior, such as a health awareness campaign, can be more effective, particularly if they reduce the number of women who simultaneously cook and care for children.

We have also examined the relation between wood-use and more general anthropometric measures of health. This analysis yields an interesting new finding. Our results strongly indicate that adverse health effects of burning wood in the home go well beyond acute respiratory infection and have much broader impacts. Furthermore, they suggest that remedial policies should be aimed directly at eliminating the use of wood fuel rather than at modifying wood burning practices or technology as we would conclude if the only adverse effect of firewood use were increased childhood ARI.

Finally, our analysis hints at another potentially very interesting finding, which deserves further attention in future research but lies outside the scope of this paper. Our results indicate that cooking with firewood in the home has an impact on traditional malnourishment measures. We cannot identify the mechanisms at work here, but they could be related to the effects that cooking with wood could have on the efficiency of nutrient absorption or directly on measured anthropometric indicators. There is a potential implication for policies to combat Third World childhood malnutrition, as measured by standard anthropometric indicators. If the impact of using firewood on these indicators has been ignored and they could therefore have been misinterpreted, then the problem they point to may have been, to some extent, misdiagnosed. Hence, policies that focus exclusively on preventing malnutrition may be mis-targeted.

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Table 1 Summary Statistics

Variable	Description	Ages 0 - 5 Mean	Ages 0 - 5 Std. Dev.	Ages 0 - 15 Mean	Ages 0 - 15 Std. Dev.
Children					
Respiratory Infection	Dummy = 1 if symptoms of respiratory infection reported	0.46	0.50	0.46	0.50
Height-for-age[a]	Height standardized by age	93.12	6.22	92.61	5.88
Weight-for-age[a]	Weight standardized by age	89.02	14.27	88.08	14.97
Age	Age in years	2.43	1.71	4.69	3.07
Female	Dummy = 1 if gender is female	0.49	0.50	0.46	0.50
Mothers					
Mother Cooks and Cares for Children	Dummy = 1 if mother both cooks and cares for children	0.84	0.37	0.78	0.42
Mother has No Education	Dummy = 1 if mother has no education	0.41	0.49	0.43	0.50
Mother's Age	Mother's Age in years	29.10	7.39	31.39	7.77
Mother is Household Head	Dummy = 1 if mother is head of household	0.07	0.26	0.08	0.28
Households					
Wood Use	Dummy = 1 if household used firewood	0.80	0.40	0.87	0.34
Wood consumption [a]	Monthly firewood consumption	412.85	614.33	453.22	595.02
Stove Ownership	Dummy = 1 if household owns gas stove	0.41	0.49	0.37	0.48
Cooking in Home	Dummy = 1 if cooking takes place inside the home	0.35	0.48	0.34	0.47
Roof Permeability	Dummy = 1 if roof permeable	0.91	0.28	0.92	0.28
Wall Permeability	Dummy = 1 if walls permeable	0.17	0.38	0.17	0.37
Price of Stove [a]	Estimated value of stove (GTQ)	774.97	585.03	771.70	590.95
Price of Wood [a]	Price firewood (GTQ/unit)	0.51	2.08	0.46	1.51
Price of Electricity [a]	Price electricity (GTQ/Kw)	1.58	5.98	1.57	4.77
Price of Coal [a]	Price coal (GTQ/lb)	2.20	2.24	2.17	1.69
Price of LPG [a]	Price LPG (GTQ/lb)	6.53	12.10	6.62	10.82
Price of Kerosene [a]	Price kerosene (GTQ/bottle)	3.63	6.04	3.69	6.99
No Credit	Dummy = 1 if no access to credit	0.36	0.48	0.40	0.49
Consumption [a]	Annual household consumption (GTQ)	30,973	27,533	27,381	22,752
Household Head Age [a]	Age head of household	40.74	12.99	39.00	11.94
Household size	Number of people in household	5.93	2.31	6.84	2.48
Rooms	Number of rooms in home	1.86	1.21	1.90	1.21
Rural	Dummy = 1 if rural household	0.63	0.48	0.63	0.48

[a] Natural logarithm of variable used for estimation.

Table 2 Stove Ownership and Wood Use Models

	Stove Ownership	*Wood Use*	
Variable	*Logit* (Dep. Var.: Stove Ownership)	*Logit* (Dep. Var.: Wood Use)	*Tobit* (Dep. Var.: ln of Wood Qty.)
Constant	-15.01***	8.89***	4.39***
	(1.04)	(1.67)	(1.37)
No Credit	-0.62***		
	(0.09)		
Price of Stove	-2.53***		
	(0.11)		
Stove Ownership		-2.68***	-1.57***
		(0.20)	(0.09)
Price of Wood	0.42***	-1.19***	-1.13***
	(0.05)	(0.12)	(0.04)
Price of Electricity	-0.31***	-0.02	-0.01
	(0.07)	(0.07)	(0.04)
Price of Coal	-0.01	0.13	0.06
	(0.13)	(0.13)	(0.10)
Price of LPG	-0.81***	0.014	0.01
	(0.07)	(0.07)	(0.05)
Price of Kerosene	-0.04	-0.24**	-0.09
	(0.08)	(0.10)	(0.06)
Consumption	3.29***	-1.67***	-0.79***
	(0.11)	(0.12)	(0.06)
Age Household Head		1.11***	0.54***
		(0.21)	(0.09)
Household Size		0.47***	0.21***
		(0.04)	(0.01)
Ethnicity Dummies		7 Dummies	
District Dummies		20 Dummies	
Log likelihood	-1677.02	-1034.37	-9455.37
Observations	5655	5124	5151

Note: *, **, *** indicate parameter significance at α = 10%, 5%, and 1% respectively

Table 3 Children's Respiratory Health

Variable	Wood Use: IV RE-Logit	Wood Use: IV FE-Linear Probability	Wood Consumption: IV RE-Logit	Wood Consumption: IV FE-Linear Probability
Constant	-2.75	0.68***	-2.97*	0.67**
	(1.83)	(0.24)	(1.81)	(0.27)
Mother Cooks and Cares for Children		-0.42**		-0.21
		(0.20)		(0.23)
Wood	0.39		- 0.06	
	(0.51)		(0.10)	
Wood × Mother Cooks and Cares for Children	0.43**	0.47**	0.07**	0.04
	(0.21)	(0.21)	(0.04)	(0.04)
Wood × Age	0.12	0.02	0.02	0.002
	(0.09)	(0.02)	(0.01)	(0.002)
Wood × Cooking in Home	0.39**		0.06**	
	(0.16)		(0.03)	
Wood × Roof Permeability	-0.42		-0.05	
	(0.38)		(0.07)	
Wood × Wall Permeability	-0.04		-0.003	
	(0.17)		(0.03)	
Age	0.34***	0.04**	0.36***	0.05***
	(0.11)	(0.02)	(0.09)	(0.02)
Age^2	-0.08***	-0.01***	-0.09***	-0.01***
	(0.02)	(0.002)	(0.02)	(0.002)
Female	0.05	-0.003	0.05	-0.003
	(0.09)	(0.01)	(0.10)	(0.01)
Mother's Age	-0.06	-0.01	-0.06	-0.01
	(0.05)	(0.02)	(0.05)	(0.02)
Mother's Age^2	6.7E-04	1.5E-04	7.2E-04	1.5E-04
	(7.8E-04)	(2.8E-04)	(8.0E-04)	(2.5E-04)
Mother has No Education	-0.17	0.01	-0.17	0.01
	(0.17)	(0.04)	(0.14)	(0.04)
Mother is Household Head	-0.12	-0.18	-0.11	-0.16
	(0.23)	(0.12)	(0.19)	(0.14)
Rural	0.53***		0.57***	
	(0.16)		(0.18)	
Consumption	0.35**		0.26	
	(0.17)		(0.22)	
Household Size	-0.08***		-0.05	
	(0.03)		(0.04)	
Rooms	-0.10		-0.11*	
	(0.07)		(0.06)	
Ethnicity Dummies	7 Dummies		7 Dummies	
District Dummies	20 Dummies		20 Dummies	
Log likelihood	-3876.09		-3897.52	
Observations	6542	6542	6576	6576

Note: *, **, *** indicate parameter significance at α = 10%, 5%, and 1% respectively

Table 4 Children's Weight for Age - Ages 0 to 5

Variable	Wood Use IV RE	Wood Use IV FE	Wood Consumption IV RE	Wood Consumption IV FE
Constant	4.44***	4.56***	4.44***	4.57***
	(0.06)	(0.09)	(0.06)	(0.11)
Mother Cooks and Cares for Children		0.16		0.03
		(0.10)		(0.09)
Wood	-0.03		-0.01**	
	(0.02)		(0.004)	
Wood × Mother Cooks and Cares for Children	-0.01**	-0.19*	-0.002**	-0.01
	(0.006)	(0.10)	(0.001)	(0.02)
Wood × Age	-0.01***	-0.01**	-0.001*	-0.001
	(0.004)	(0.006)	(0.0006)	(0.0007)
Wood × Cooking in Home	-0.01*		-0.001*	
	(0.004)		(0.0008)	
Wood × Roof Permeability	0.002		0.002	
	(0.01)		(0.002)	
Wood × Wall Permeability	0.1E-03		0.001	
	(0.006)		(0.001)	
Age	-0.06***	-0.06***	-0.06***	-0.06***
	(0.01)	(0.01)	(0.01)	(0.01)
Age^2	0.01***	0.01***	0.01***	0.01***
	(0.001)	(0.001)	(0.001)	(0.001)
Female	0.01***	0.01***	0.01***	0.01***
	(0.003)	(0.005)	(0.003)	(0.005)
Mother's Age	-0.004**	-0.003	-0.003	-0.003
	(0.002)	(0.005)	(0.002)	(0.007)
Mother's Age^2	0.7E-03**	0.5E-03	0.6E-03*	0.5E-03
	(0.3E-03)	(0.8E-03)	(0.3E-03)	(1.1E-03)
Mother has No Education	-0.01**	0.01	-0.01**	0.01
	(0.005)	(0.02)	(0.004)	(0.02)
Mother is Household Head	-0.01*	-0.08	-0.02*	-0.09
	(0.008)	(0.06)	(0.008)	(0.07)
Rural	-0.02***		-0.02***	
	(0.01)		(0.005)	
Consumption	0.02***		0.02***	
	(0.01)		(0.005)	
Household Size	-0.01***		-0.007***	
	(0.001)		(0.001)	
Rooms	0.01***		0.01***	
	(0.002)		(0.002)	
Ethnicity Dummies	7 Dummies	7 Dummies	7 Dummies	7 Dummies
District Dummies	20 Dummies		20 Dummies	
Observations	5798	5798	5831	5831

Note: *, **, *** indicate parameter significance at α = 10%, 5%, and 1% respectively

Table 5 Children's Weight for Age - Ages 0 to 15

	Wood Use		Wood Consumption	
Variable	*IV RE*	*IV FE*	*IV RE*	*IV FE*
Constant	4.32***	4.56***	4.25***	4.54***
	(0.05)	(0.08)	(0.06)	(0.07)
Mother Cooks and Cares for Children		0.09		0.08
		(0.07)		(0.06)
Wood	-0.02		-0.003	
	(0.02)		(0.003)	
Wood × Mother Cooks and Cares for Children	-0.01**	-0.10	-0.002**	-0.01
	(0.005)	(0.07)	(0.001)	(0.01)
Wood × Age	-0.01***	-0.01***	-0.001***	-0.001***
	(0.002)	(0.003)	(0.0003)	(0.0004)
Wood × Cooking in Home	-0.01**		-0.002***	
	(0.005)		(0.001)	
Wood × Roof Permeability	0.003		0.001	
	(0.01)		(0.002)	
Wood × Wall Permeability	-0.004		-0.0002	
	(0.005)		(0.0009)	
Age	-0.01***	-0.01***	-0.01***	-0.01***
	(0.002)	(0.003)	(0.002)	(0.003)
Age^2	0.001***	0.001***	0.001***	0.001***
	(0.0002)	(0.0002)	(0.0001)	(0.0002)
Female	0.01**	0.01**	0.01**	0.01**
	(0.003)	(0.003)	(0.003)	(0.003)
Mother's Age	-0.002**	-0.002	-0.002	-0.001
	(0.001)	(0.005)	(0.002)	(0.004)
Mother's Age^2	0.5E-03**	0.3E-03	0.4E-03*	0.2E-03
	(0.2E-03)	(0.7E-03)	(0.2E-03)	(0.7E-03)
Mother has No Education	-0.01***	0.01	-0.01**	0.01
	(0.003)	(0.02)	(0.004)	(0.02)
Mother is Household Head	-0.01*	-0.04	-0.02*	-0.01
	(0.008)	(0.06)	(0.008)	(0.04)
Rural	-0.02***		-0.02***	
	(0.003)		(0.004)	
Consumption	0.03***		0.03***	
	(0.01)		(0.006)	
Household Size	-0.01***		-0.01***	
	(0.001)		(0.001)	
Rooms	0.01***		0.01***	
	(0.002)		(0.002)	
Ethnicity Dummies	7 Dummies	7 Dummies	7 Dummies	7 Dummies
District Dummies	20 Dummies		20 Dummies	
Observations	9867	9867	9923	9923

Note: *, **, *** indicate parameter significance at α = 10%, 5%, and 1% respectively

Table 6 Children's Height for Age - Ages 0 to 5

	Wood Use		*Wood Consumption*	
Variable	*IV RE*	*IV FE*	*IV RE*	*IV FE*
Constant	4.50***	4.60***	4.50***	4.60***
	(0.02)	(0.04)	(0.02)	(0.04)
Mother Cooks and Cares for Children		0.02		-0.004
		(0.02)		(0.02)
Wood	-0.002		-0.0001	
	(0.009)		(0.001)	
Wood × Mother Cooks and Cares for Children	-0.01***	-0.03	-0.001***	0.0002
	(0.002)	(0.02)	(0.0004)	(0.005)
Wood × Age	-0.01***	-0.008***	-0.001***	-0.002***
	(0.002)	(0.003)	(0.0002)	(0.0003)
Wood × Cooking in Home	-0.003		-0.001*	
	(0.002)		(0.0003)	
Wood × Roof Permeability	-0.003		-0.0002	
	(0.01)		(0.0008)	
Wood × Wall Permeability	-0.004*		-0.0005	
	(0.002)		(0.0004)	
Age	-0.03***	-0.03***	-0.03***	-0.03***
	(0.002)	(0.003)	(0.002)	(0.003)
Age^2	0.01***	0.01***	0.01***	0.01***
	(0.003)	(0.0004)	(0.0002)	(0.0003)
Female	0.002	0.002	0.002	0.002
	(0.002)	(0.002)	(0.001)	(0.002)
Mother's Age	-0.0003**	-0.002	-0.7E-03	-0.003
	(0.0005)	(0.002)	(0.001)	(0.002)
Mother's Age^2	0.1E-03	0.4E-03	0.8E-07	0.4E-03
	(0.8E-07)	(0.4E-03)	(1.0E-07)	(0.4E-03)
Mother has No Education	-0.01***	-0.004	-0.01***	-0.002
	(0.002)	(0.008)	(0.002)	(0.01)
Mother is Household Head	-0.001	-0.02	-0.002	-0.02
	(0.003)	(0.02)	(0.004)	(0.02)
Rural	-0.01***		-0.005***	
	(0.002)		(0.002)	
Consumption	0.01***		0.01***	
	(0.002)		(0.002)	
Household Size	-0.003***		-0.003***	
	(0.0005)		(0.0004)	
Rooms	0.004***		0.004***	
	(0.0009)		(0.001)	
Ethnicity Dummies	7 Dummies	7 Dummies	7 Dummies	7 Dummies
District Dummies	20 Dummies		20 Dummies	
Observations	5798	5798	5831	5831

Note: *, **, *** indicate parameter significance at α = 10%, 5%, and 1% respectively

Table 7 Children's Height for Age - Ages 0 to 15

	Wood Use		*Wood Consumption*	
Variable	*IV RE*	*IV FE*	*IV RE*	*IV FE*
Constant	4.46***	4.59***	4.48***	4.59***
	(0.02)	(0.04)	(0.02)	(0.04)
Mother Cooks and Cares for Children		0.02		0.005
		(0.02)		(0.03)
Wood	-0.008		-0.002*	
	(0.006)		(0.001)	
Wood × Mother Cooks and Cares for Children	-0.004**	-0.02	-0.001**	-0.0002
	(0.002)	(0.02)	(0.0003)	(0.005)
Wood × Age	-0.001	-0.001	-0.0002*	-0.0003**
	(0.001)	(0.001)	(0.0001)	(0.0001)
Wood × Cooking in Home	-0.005***		-0.001***	
	(0.002)		(0.0003)	
Wood × Roof Permeability	-0.004		-0.001	
	(0.004)		(0.001)	
Wood × Wall Permeability	-0.005**		-0.001	
	(0.002)		(0.0004)	
Age	-0.02***	-0.02***	-0.02***	-0.02***
	(0.001)	(0.001)	(0.001)	(0.001)
Age^2	0.001***	0.001***	0.001***	0.001***
	(0.0001)	(0.0001)	(0.0001)	(0.0001)
Female	0.003***	0.003**	0.003***	0.003***
	(0.001)	(0.001)	(0.001)	(0.001)
Mother's Age	-0.0003**	-0.001	0.0001	-0.001
	(0.0005)	(0.002)	(0.0005)	(0.001)
Mother's Age^2	0.1E-03	0.2E-03	0.4E-07	0.2E-03
	(0.8E-07)	(0.3E-03)	(0.7E-07)	(0.2E-03)
Mother has No Education	-0.01***	-0.007	-0.01***	-0.01
	(0.001)	(0.008)	(0.002)	(0.01)
Mother is Household Head	-0.001	0.01	-0.002	0.01
	(0.003)	(0.01)	(0.003)	(0.01)
Rural	-0.01***		-0.005***	
	(0.001)		(0.002)	
Consumption	0.01***		0.01***	
	(0.002)		(0.002)	
Household Size	-0.003***		-0.003***	
	(0.0004)		(0.0004)	
Rooms	0.004***		0.004***	
	(0.0007)		(0.001)	
Ethnicity Dummies	7 Dummies	7 Dummies	7 Dummies	7 Dummies
District Dummies	20 Dummies		20 Dummies	
Observations	9867	9867	9923	9923

Note: *, **, *** indicate parameter significance at α = 10%, 5%, and 1% respectively

Table 8 Impact of Wood Burning on Weight for Age and Height for Age

Variable	*AGE 0 to 5*	*AGE 0 to 15*	*AGE 0 to 5*	*AGE 0 to 15*
		Observed Sample Values		
Weight for Age Percentile (WAM)	89.02	88.08	89.02	88.08
	(14.27)	(14.97)	(14.27)	(14.97)
Height for Age Percentile (HAM)	93.12	92.61	93.12	92.61
	(6.22)	(5.88)	(6.22)	(5.88)
Weight for Age Z-Score (WAZ)	-1.05	-1.04	-1.05	-1.04
	(1.24)	(1.15)	(1.24)	(1.15)
Height for Age Z-Score (HAZ)	-1.73	-1.76	-1.73	-1.76
	(1.55)	(1.41)	(1.55)	(1.41)
Severe Malnourishment (% with WAZ<-2)	21%	18%	21%	18%
Severe Stunting (% with HAZ<-2)	44%	44%	44%	44%
	Wood Use Dummy in Model		*Wood Use Quantity in Model*	
	Model Fit		***Model Fit***	
Predicted WAM from model	88.75	87.71	88.75	87.71
	(12.30)	(12.32)	(12.30)	(12.32)
Predicted HAM from model	93.08	92.55	93.08	92.55
	(5.54)	(4.94)	(5.54)	(4.94)
Predicted WAZ from model	-1.07	-1.07	-1.07	-1.07
	(1.06)	(0.93)	(1.06)	(0.93)
Predicted HAZ from model	-1.74	-1.78	-1.74	-1.78
	(1.38)	(1.18)	(1.38)	(1.18)
Predicted Severe Malnourishment (%)	16.8%	11.8%	16.8%	11.8%
Predicted Severe Stunting (%)	43%	43%	43%	43%
	Simulations		***Simulations***	
Predicted WAM with no wood	104.85	97.13	94.88	95.89
	(14.60)	(12.63)	(12.32)	(12.38)
Predicted HAM with no wood	96.34	93.87	94.28	92.96
	(5.19)	(4.82)	(5.24)	(4.86)
Predicted WAZ with no wood	0.31	-0.36	-0.55	-0.45
	(1.26)	(0.96)	(1.06)	(0.94)
Predicted HAZ with no wood	-0.92	-1.46	-1.44	-1.68
	(1.30)	(1.15)	(1.31)	(1.16)
Severly Malnourished with No Wood (%)	2%	2%	6%	2%
Predicted Stunting No Wood (%)	20%	32%	33%	39%

Standard errors in parentheses.