Indoor Air Pollution in India and a Baby's Size at Birth: Is there a Link?

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Abstract

An association between exposure to biofuels and adverse pregnancy outcomes has been reported in some developing countries of Asia and Latin America. In India, where more than 70% of households use biomass for cooking and heating purposes, hardly any research has been done to find out if there is a possible link between exposure to biofuels and adverse pregnancy outcomes. In the present study, an attempt has been made to find out if there is a plausible link between indoor air pollution (as determined by exposure to biofuels) and a baby's size at birth (a proxy for low birth weight), in India, by using data from the National Family Health Survey, 1998–99. The results of logistic regressions show that using biomass as cooking fuel is a very significant predictor in determining a baby's size at birth, even after controlling for a number of confounding variables. In addition, there are other demographic, socio-economic and spatial characteristics that have a very significant influence in determining the size of a baby at birth in India.

Introduction

Contrary to the common perception that air pollution is primarily an urban phenomenon associated with industries and motor vehicles, the problem of indoor air pollution due to use of unprocessed biomass fuels far outweighs that of ambient air pollution in developing countries. Approximately half of the world's population and up to 90% of rural households in developing countries still rely on unprocessed biomass fuels such as wood, dung and crop residues (World Resources Institute 1998). According to the Census of India 2001, more than 72% of households still use unprocessed biomass as cooking fuel. In rural areas this is around 90% (Office of the Registrar General India 2003). It is estimated that some 3.5 billion people, mostly in the rural areas of developing countries, are exposed to high levels of air pollutants in their homes (World Bank 1992). Although overall use of biomass fuel has been projected to decline over the coming years, reliance on biomass fuel as a major source of energy will remain substantial in the foreseeable future (World Bank 1996; WRI 1998; World Energy Council (WEC) 1999).

Biomass smoke contains many noxious components, including respirable particulates, carbon monoxide, nitrogen oxides, formaldehyde and polyaromatic hydrocarbons (Smith 1987, 1993; WHO 1992). High exposure to these pollutants has been shown to cause serious health hazards such as acute respiratory infections (ARI), chronic obstructive lung disease, tuberculosis, blindness, asthma and lung cancer (Kossove 1982; de Koning et al. 1985; Pandey et al. 1989; Armstrong and Campbell 1991; Dhar and Pathania 1991; Perez-Padilla et al. 1996; Mishra and Retherford 1997; Mishra et al. 1999a, 1999b, 2000, 2002; Bruce et al. 2000). It is estimated that about half a million women and children die every year from indoor air pollution in India (Smith 2000a). Compared to other countries, India has among the largest burden of disease due to the use of unclean household fuels, and 28% of all deaths due to indoor air pollution in developing countries occur in India (Smith 2000a).

Plausible Mechanism

Adverse pregnancy outcomes, such as low birth weight (LBW), still birth and perinatal mortality, are believed to be linked with indoor air pollution, though the mechanisms are only partially known. During pregnancy, women naturally produce carbon monoxide internally, and the natural rate of internal carbon monoxide production can be up to 50% higher than normal levels. As a consequence, women have higher levels of natural carboxyhemoglobin (HbCO) levels during pregnancy (Linderholm and Lundstrom 1969). Pregnant women's blood has 20–30% lower oxygen-carrying capacity due to lower concentration of hemoglobin (Longo 1977). Levels of carbon monoxide in houses using biomass fuels are high enough to raise a person's carboxyhemoglobin to levels comparable to those found in smokers (Dary et al. 1981; Behera et al. 1998). Thus, there is a probability that pregnant women who inhale carbon monoxide due to use of unprocessed biomass fuels can be at higher risk of spontaneous abortions, still births and reduced birth weights. It is worth mentioning that LBW, intrauterine growth retardation (IUGR) and impaired growth in the early years of life are known to influence the subsequent health status of individuals, including increased mortality and morbidity in childhood and an elevated risk of hypertension and coronary heart disease (Barker 1995; Osmond and Baker 2000; Smith 2000a). It is estimated that adverse pregnancy outcomes are responsible for 6% of all deaths, 7.5% of the overall national burden of disease and 20% of the national burden of disease for under-five children in India (Smith 2000a).

Very limited studies have been conducted in developing countries to identify plausible links between unfavourable birth outcomes and indoor air pollution. In India, hardly any large-scale studies have been carried out in this regard. Only one study in India seems to have examined adverse pregnancy outcomes as an outcome of biomass fuel use. This study, carried out in Ahmedabad, found an excess risk of 50% of still births among women using biomass fuels during pregnancy (Mavalankar et al. 1991). In rural Guatemala, babies born to women using wood fuel were 63 grams lighter than those born to women using gas and electricity, even after controlling for all other socio-economic and maternal factors (Boy et al. 2002). A Chinese study of urban ambient air pollution also found a strong relationship of particulate levels with preterm delivery (Xu et al. 1995a). The same group found that particulate air pollution was also associated with LBW (Wang et al. 1997). Some studies have also shown that intrauterine mortality, LBW, pre-maturity and early infant death have been strongly associated with urban ambient air pollution at much lower concentrations than in biomass fuel-using households (Pereira et al. 1998; Ritz and Yu 1999; Scram 1999; Bobak 2000).

Along with biomass fuels, other spatial, demographic and socio-economic factors may also adversely affect birth outcomes in developing countries. It has been found that risks of unfavourable birth outcomes are higher: for very young mothers, or those aged over 35 years; for women in their first pregnancy or after four pregnancies; when there is a short interval between two pregnancies; for women with certain pre-existing health problems related to their reproductive tracts; for poor, malnourished and uneducated women; and for those women who do not have easy access to adequate healthcare (Herz and Measham 1987; Anandalakshmy et al. 1993; Bhargava et al. 1991; World Health Organization 1994; Population Studies and Research Institute (PSRI) and UNICEF 1996; Magadi et al. 2001). But some contradictory results on the effects of education and occupation have been found in Burkina Faso (Prazuck et al. 1993). A number of studies have demonstrated an association between antenatal care and adverse pregnancy outcomes such as perinatal mortality, LBW and premature delivery (Sadio 1991; Coria-Soto et al. 1996; Hollander 1997; Magadi et al. 2001). Some studies have found that poor maternal nutrition is one of the key factors closely associated with LBW, perinatal mortality and other forms of adverse pregnancy outcome (Voorhoeve et al. 1984; Mavalankar et al. 1991; Achadi et al. 1995; Pelletier et al. 1995; Magadi et al. 2001). Behavioural factors such as tobacco smoking have been found to be an important cause of intrauterine growth retardation and reduced birth weight (Seidman and Mashiach 1991; Gidding et al. 1994; Longo 1977).

The present study seeks to examine the influence of the use of biomass as cooking fuel on a baby's size at birth, in India, after controlling for a number of plausible spatial, demographic and socio-cultural variables that may affect birth outcomes unfavourably.

Materials and Methods

Data

Data for this study were drawn from India's second National Family Health Survey (NFHS-2), a large-scale survey carried out between 1998 and 1999 by ORC Macro and the International Institute for Population Sciences (IIPS). The data on fertility, mortality, morbidity, family planning and important aspects of reproductive health, nutrition and child care were collected from a nationally representative sample of 90,303 ever-married women in the age group 15–49 years, residing in 92,486 households. In addition, the survey collected information on 33,026 children born to those women during the three years preceding the survey. However, the analysis regarding the size of babies at birth is based on 32,470 of these children, for which there was complete information on the variables used in the analysis.

Response Variable

The analysis on how indoor air pollution affects a baby's size at birth presented in this paper is based on mothers' reports for the outcome variable – "small or smaller than average size of the baby at birth." Reporting may be unreliable for the outcome due to possibility of personal biases. Measurement error is likely to be critical for the size of a baby at birth, which is subject to personal perceptions and possible systematic errors.

It must be mentioned that, in a developing country, such as India, more than 70% of babies are not weighed at birth, since most of the deliveries take place at home. It is worth noting that, out of 33,026 surveyed children in NFHS-2, only 8,504 were weighed at birth. In those cases in which the babies were weighed at birth, the possibility of selective representation of some socio-economic groups in the sample distribution may not be ruled out. Table 1 clearly reveals that those babies who were weighed at birth were of higher-educated, middle-aged and well-nourished mothers and belonged to the economically better off section of society. High urban bias has also been observed in this case. Again, from Table 1, it can be noted that those mothers who received complete antenatal care are more likely to have their baby weighed at birth. Table 1 also shows that the weighed babies are basically representative of those households that use cleaner fuels for cooking and heating purposes. Thus, using actual birth weight as a response variable in the present analysis would not be worthwhile, as it may produce biased estimates of the predictor variables and could distort the actual scenario. As such, actual birth weight has not been considered in the initial analysis and an alternate scheme of analysis has been adopted in which actual birth weight has been considered as response variable. Results are presented in a subsequent section.

Table 1. Number and sample distribution of births in the last three years for selected variables used in the analysis by weighed status, India, NFHS-2, 1998–99

Variables	Not weighed at birth		Weighed at birth	
	Number	Percentage	Number	Percentage
Type of cooking fuel				
Biomass fuels	20,854	86.1	3,849	45.3
Cleaner fuels	3,353	13.9	4,655	54.7
Sex				
Male	12,508	51.7	4,566	53.7
Female	11,699	48.3	3,938	46.3
Birth order/birth interval				
First birth	5,720	23.6	3,838	45.1
Birth order 2–3/<24 months birth int.	2,634	10.9	929	10.9
Birth order 2–3/≥24 months birth int.	7,724	31.9	2,833	33.3
Birth order 4+/<24 months birth int.	1,690	7.0	207	2.4
Birth order 4+/≥24 months birth int.	6,439	26.6	697	8.2
Mother's age				
<20	5,213	21.5	1,444	17.0
20–29	14,336	59.2	5,710	67.1
30+	4,658	19.2	1,350	15.9
Religion/caste				
Forward caste Hindu	11,135	46.0	4,772	56.1
SC-ST Hindua	6,900	28.5	1,282	15.1
Other than Hindu	6,172	25.5	2,450	28.8
Maternal education				
Illiterate	16,289	67.3	1,738	20.4
Primary-middle completed	6,089	25.2	3,444	40.5
Higher-educated	1,825	7.5	3,320	39.0
Standard of living				
Low	9,350	39.1	1,237	14.8
Medium	11,731	49.0	4,041	48.3
High	2,843	11.9	3,087	36.9
Mother's BMI				
<18.5 kg/m^2	8,316	37.7	2,286	28.0
≥18.5 kg/m^2	13,756	62.3	5,884	72.0
Complete antenatal care				
No	17,381	71.8	1,999	23.5
Yes	6,826	28.2	6,505	76.5
Place of residence				
Rural	20,207	83.5	4,089	48.1
Urban	4,000	16.5	4,415	51.9
Geographic region				
North	6,351	26.2	1,354	15.9
Central	6,582	27.2	575	6.8
South	1,889	7.8	2,522	29.7
West	1,628	6.7	1,747	20.5
East & North-east	7,757	32.0	2,306	27.1
Number of births*	**24,207**	**100.0**	**8,504**	**100.0**

*Number of births varies slightly depending on the number of missing cases at each variable.
a- Scheduled castes and scheduled tribes

Some previous studies have addressed the issue of the reliability of mothers' reports of the size of their babies at birth, and found that mothers' reports, including approximate sizes, are fairly reliable and can be used as proxies to examine biological and socio-economic correlates of birth weight (Da Vanzo et al. 1984; Boerma et al. 1996; Magadi et al. 2001).

To assess the reliability of a mother's perception of the size of her baby at birth, the average weights of the babies by reported sizes were examined in cases where birth weights were independently available (shown in Table 2), and the test of association (Somers' D test) between perceived size and actual birth weights, when available, was performed. It has been found that, given two babies in the sample chosen at random, the odds are more than three to one that a baby perceived as heavier at birth actually has greater birth weight. Note, however, that only 1,905 babies perceived as average actually have birth weights between 2,300 and 2,900 grams, whereas 2,481 babies perceived as average have birth weights above 2,900 grams. Possibly for this reason that the Somers' D test on the degree of association between these two variables did not confirm their very close agreement.

Table 2. Association between birth weight (in grams) and reported baby size, India, NFHS-2, 1998–99

	Perceived size of baby at birth				
Birth weight (g)	**Larger than average**	**Average**	**Smaller than average**	**Very small**	**Total**
>2,900	1,550	2,481	156	15	4,202
>2,300 and ≤2,900	163	1,905	537	52	2,657
>1,900 and ≤2,300	55	580	488	90	1,213
≤1,900	16	141	258	162	577
Total	**1,784**	**5,107**	**1,439**	**319**	**8,649**

		Value	**Asymp. std. error**	**Approx. sig.**
Somers' d	Symmetric	0.495	0.007	.000
	Birth weight (kg) – Dependent	0.523	0.007	.000
	Size of child at birth – Dependent	0.469	0.008	.000

Note that the main objective of the present study is to observe the effect of cooking fuel on a baby's size at birth by performing multivariate analyses, where the response variable is dichotomous (<average and ≥average) in nature. To assess whether mothers' reports affects the multivariate analyses in any way, the data have been further re-classified into actual birth weight (categories are: <2,500 grams and ≥2,500 grams; as according to WHO and UNICEF 1992, LBW is defined as a baby's weight at birth being <2,500 grams), on the one hand, and perceived size at birth (categories are: <average and ≥ average) on the other. Here, the two categories "smaller than average" and "very small" have been pooled into "<average" category and "larger than average" and "average" have together been combined into "≥average" category. The results are presented in Table 3. Table 3 clearly reveals that, of the babies perceived as less than average size at birth, about 54% actually have birth weight less than 2,500 grams (1,037 babies out of a total of 1,928), whereas of the babies perceived as equal or greater than average size at birth more than 87% actually have birth weight equal or greater than 2,500 grams (6,000 babies out of a total of 6,721 babies). These findings suggest that mothers' reports were reasonably reliable, at least for the purpose of the present analysis. However, it is assumed that mothers whose babies were not weighed reported using a similar scale as for those mothers whose babies were weighed.

Table 3. Association between birth weight (in grams) and reported baby size (pooled for multivariate analysis), India, NFHS-2, 1998–99

	Perceived size of baby at birth		
Birth weight (g)	Less than average	Greater than or equal to average	Total
<2,500	1,037	891	1,928
≥2,500	721	6,000	6,721
Total	**1,758**	**6,891**	**8,649**

Predictor and Control Variables

The main predictor variable in this analysis has been created by the combination of two variables: (a) "type of fuel mainly used for cooking" and (b) "other types of fuel commonly used for cooking or heating." Fuel type has also been shown in India to be a good predictor of indoor air pollution levels in households (Mehta 2002; Mishra 2003). The NFHS collected data on a tenfold classification of primary cooking fuel, including wood, crop residues, dung cakes, coal/coke/lignite, charcoal, kerosene, electricity, liquefied petroleum gas (LPG), biogas and a residual category of other fuels. Measurements in India show that the emissions of pollutants from household stoves vary along the "energy ladder," with solid fuels producing substantially more pollution per meal cooked than liquid or gaseous fuels (Smith et al. 2000). It is worth mentioning that in India, as in other South Asian countries, women generally cook under poorly ventilated conditions using biomass fuels, such as wood, crop residues or dung cakes, either in pits or in open U-shaped stoves, called *chulhas*. These stoves are immovable, burn biomass inefficiently and release high volumes of noxious air pollutants, as mentioned earlier. Also, fires from biomass fuels require continuous feeding of biomass to the stove, which results in extended exposure to the noxious pollutants. Though coal, coke and lignite produce similar levels of pollutants as biomass fuels, they are usually burned on portable stoves that are often put on in a courtyard or open area and brought indoors only when the fuels start burning cleanly. Most of the smoke is released outdoors within the first few minutes of the fire's ignition (Mishra and Retherford 1997).

Keeping the above observations in mind, the main predictor variable "type of cooking fuel" (actually meaning "type of fuel used for cooking and heating purposes") has been grouped into two categories: biomass fuels (wood, crop residues or dung cakes) and cleaner fuels (coal/coke/lignite, charcoal, kerosene, electricity, LPG or biogas). The very small category (0.1 %) of "other fuels" has also been included in the category of cleaner fuel.

In addition to cooking smoke, it has been found in various studies that smoking tobacco is also a very significant predictor of adverse pregnancy outcomes (e.g., Mishra et al. 2005). According to NFHS-2 data, in India 97.5% of females more than 15 years of age do not currently smoke tobacco and 97.2% have never smoked. Thus, in spite of immense negative consequences of tobacco smoking on pregnancy outcomes, the effect of this factor cannot be studied, since there is hardly any variation in the level of non-smoking among females in India. Passive smoking or environmental tobacco smoke (ETS), which may be an important determinant of unfavourable birth outcomes, has also not been included in the analysis due to the difficulty of measuring actual exposure levels.

Because the effects of exposure to cooking smoke on the risk of a baby's size at birth are likely to be confounded, either directly or indirectly, by the effects of other risk factors, as suggested by previous studies, it is necessary to statistically control, or adjust, for such factors. The variables included as controls in the analysis on a baby's size at birth are: mother's age (younger than 20, 20–29 and 30 or more years); sex of the child (male, female); maternal education (illiterate, primary-middle completed, higher-educated); mother's body mass index (BMI) (less than 18.5 kg/m^2, greater than or equal to 18.5 kg/m^2); standard of living index[1] (low, medium, high); receiving complete antenatal care[2] (no, yes); place of residence (rural, urban) and geographic region[3] (north, central, south, west and, east and north-east). Birth order and birth interval have been combined to form a single variable and then controlled for. Birth order and birth interval have been categorized as: first birth, birth order two or three with less than 24 months of birth interval, birth order two or three with equal or more than 24 months of birth interval, birth order four and above with less than 24 months of birth interval, birth order four and above with equal or more than 24 months of birth interval. Religion and caste have been pooled and then controlled for (forward caste Hindu, scheduled caste/scheduled tribe Hindu and other than Hindu).[4]

Method

The analysis focuses on how use of biomass cooking fuels affects a baby's size at birth, after controlling for all these potentially confounding variables. Since two categories exist for the response variable: whether the size of the baby at birth is below average or not, employing logistic regression would be best, rather than multiple regressions (Retherford and Choe 1993). Three different sets of logistic regressions have been conducted to see how various factors affect the response variable at different stages of analyses. In Model 1, only child-level variables viz. sex of the child and birth order/birth interval have been controlled for using the main predictor variable; in Model 2, maternal- and household-level characteristics, such as mother's age at child birth, religion/caste, educational attainment, standard of living, mother's BMI and complete antenatal care for the mother, have been included as control variables along with those of Model 1. In the final model (Model 3), spatial characteristics, such as place of residence and region of residence, have been incorporated into Model 2 and controlled for using the main predictor. The generalized logistic regression equation can be written in the following form:

$$\text{logit } q = \beta_0 + \beta\ \beta_i X_i \quad (i = 1,2, \ldots\ldots,n)$$

where q is the probability that the size of the baby is below average.

logit q = ln [q/(1-q)] and $\{X_i\}$ (i = 1, 2….,n) are the predictor variables, β_0 is the intercept and β_i (i = 1, 2, ……,n) the regression coefficient(s). The results of the logistic regressions of these equations are transformed into simple cross-tabulations of the probability of below-average baby size (small-sized baby) at birth using multiple classification analysis (Retherford and Choe 1993). This involves calculating adjusted values of the response variable for each category of predictor variable from the logistic regression coefficients, keeping other predictor variables at average values/distributions.

Results

Gross Differentials

Gross differentials in a baby's small size at birth by use of cooking fuel and other selected background characteristics can be observed in Table 4. First, the children of those households using unprocessed biomass as cooking fuel are at significantly higher risk of being born small-sized than the children of households using cleaner fuels. The finding reveals that nearly 27% of babies were small-sized at birth in the households using biomass as cooking fuel, whereas this is just above 20% in those households using cleaner fuels. Second, female babies are more likely to be born small-sized than male babies. Third, the second and third order children, born with a minimum spacing of 24 months, are less likely to be born small-sized. Fourth, the children of adolescent mothers are also less likely to be born small-sized.

Among socio-economic characteristics, it has been noted that illiterate, undernourished mothers and mothers belonging to poor households are significantly more likely to deliver small-sized babies. It has also been found that there is a strong negative relationship between mothers who have received complete antenatal care and the birth size of their baby. The differentials according to the place and region of residence can be noticed in the bivariate analysis.

Table 4. Number and percentage of children whose size at birth were below average by type of cooking fuel and other selected background characteristics, India, NFHS-2, 1998–99

Predictors	Number	Percentage
Type of cooking fuel		
Biomass fuels	24,491	26.8
Cleaner fuels	7,979	20.2
Sex		
Male	16,957	23.6
Female	15,513	27.0
Birth order/birth interval		
First birth	9,525	25.3
Birth order 2–3/<24 months birth int.	3,552	26.0
Birth order 2–3/≥24 months birth int.	10,494	23.8
Birth order 4+/<24 months birth int.	1,880	25.7
Birth order 4+/≥24 months birth int.	7,019	26.5
Mother's age		
<20	6,625	28.0
20–29	19,896	24.5
30+	5,949	24.5
Religion/caste		
Forward caste Hindu	15,832	24.6
SC-ST Hindua	8,112	27.2
Other than Hindu	8,526	24.3
Maternal education		
Illiterate	17,829	27.9
Primary-middle completed	9,494	24.5
Higher-educated	5,141	16.9
Standard of living		
Low	10,467	25.6
Medium	15,659	27.8
High	5,930	19.4
Mother's BMI		
<18.5 kg/m^2	10,527	29.3
≥18.5 kg/m^2	19,495	23.2
Complete antenatal care		
No	19,190	27.3
Yes	13,280	22.2
Place of residence		
Rural	24,080	26.0
Urban	8,390	22.8
Geographic region		
North	7,656	26.7
Central	7,099	28.0
South	4,388	25.3
West	3,369	24.5
East & North-east	9,958	22.1
Number of births*	**32,470**	**25.2**

*Number of births varies slightly depending on the number of missing cases at each variable.
a- Scheduled castes and scheduled tribes

Net Differentials

Net differentials of the effects of cooking fuels and selected demographic, socio-economic and spatial variables on the risk of a baby's size at birth have been estimated by using three alternative models. Model 1, in Table 5, shows that the effect of cooking fuel on a baby's size at birth becomes significantly higher when the child's sex, birth order and birth interval are statistically controlled for. Children born to mothers using biomass fuels are at 6.5 percentage points higher risk of being small-sized at birth compared to children born to mothers using cleaner fuels. Interestingly, girls tend to be significantly lighter in weight than boys at birth. The second and third order children, born with a minimum spacing of 24 months, are at significantly lower risk of being small-sized at birth than other children.

Table 5. Predicted probability of children whose size at birth was below average by type of cooking fuel and other selected background characteristics, India, NFHS-2, 1998–99

Predictors	Model 1	Model 2	Model 3
Type of cooking fuel			
Biomass fuels	26.7**	25.4**	25.5**
Cleaner fuels (ref.)	20.2	23.4	22.8
Sex			
Male (ref.)	23.5	23.5	23.4
Female	26.7**	26.6**	26.5**
Birth order/birth interval			
First birth (ref.)	25.6	26.4	26.5
Birth order 2–3/<24 months birth int.	26.0	25.8	25.6
Birth order 2–3/≥24 months birth int.	23.8**	23.8**	23.8**
Birth order 4+/<24 months birth int.	24.9	23.7*	23.2**
Birth order 4+/≥24 months birth int.	25.5	24.6*	24.3*
Mother's age			
<20		25.8	25.4
20–29 (ref.)		24.8	24.7
30+		24.5	24.7
Religion/caste			
Forward caste Hindu (ref.)		25.1	24.7
SC-ST Hindua		25.1	24.7
Other than Hindu		24.6	25.3
Maternal education			
Illiterate (ref.)		27.0	26.5
Primary-middle completed		24.7**	25.2*
Higher-educated		19.1**	19.2**
Standard of living			
Low		25.3	26.3
Medium (ref.)		25.4	25.0*
High		23.4*	22.0**
Mother's BMI			
<18.5 kg/m^2		28.2**	28.0**
≥18.5 kg/m^2 (ref.)		23.3	23.2
Complete antenatal care			
No (ref.)		25.9	25.9
Yes		23.6**	23.4**

Table 5 continued

Place of residence			
Rural (ref.)			24.5
Urban			25.9
Geographic region			
North (ref.)			27.2
Central			27.9
South			26.0
West			25.0*
East & North-east			20.9**
Number of births	**32,470**	**29,665**	**29,665**

Note: Adjusted probabilities are estimated by logistic regression. For any given predictor variable, the set of control variables consists of all other predictor variables shown in the table. When calculating adjusted percentages for categories of a given predictor variable, other variables are held constant at their mean values (for details, see Retherford and Choe 1993).
ref: Reference category
a- Scheduled castes and scheduled tribes
*p<.05, **p<.01

In Model 2, even when additional variables, such as maternal characteristics (age at childbirth, BMI, education, caste and religion, receiving antenatal care and household living standard), are controlled for, the effect of cooking with biomass fuels on a baby's size at birth remains significant, but decreased. In Model 2, children born to mothers using biomass fuels are at two percentage points higher risk of being small-sized at birth compared to children born to mothers using cleaner fuels. Except mother's age at childbirth, religion and caste, all other control variables in Model 2 have a very significant effect on a baby's size at birth. Illiterate mothers are at nearly eight percentage points higher risk of delivering a small-sized baby than their higher-educated counterparts. As expected, a mother's BMI has a large positive effect on the size of a baby at birth. Mothers whose BMI is less than 18.5 kg/m^2 are at nearly five percentage points higher risk of delivering a small-sized baby. Also, receiving complete antenatal care during pregnancy has a positive significant effect in determining a baby's size at birth. The lower risk of delivering small-sized children belonging to the mothers of affluent households compared to the mothers of poorer households stands at two percentage points.

In the complete model (Model 3), when all child characteristics, maternal characteristics, household standard of living, as well as place and region of residence are controlled for, the effect of cooking with biofuels on the size of a baby is further sharpened. It has been found that those children born to mothers using highly polluting biomass fuels have a nearly three percentage points higher probability of being born small-sized, compared to those born to mothers using cleaner fuels. Additionally, controlling for place and region of residence in Model 3 makes virtually no difference in the effects of the Model 1 and Model 2 control variables, though region of residence shows significant effect in determining a baby's size at birth. Children of the western part as well as the east and north-eastern regions of the country are at significantly lower risk of being born small-sized.

Alternate Analysis

In the preceding analysis, a baby's size at birth has been considered as a response variable because of non-availability of birth weight for a large number of children. As described earlier, out of the 33,026 children, actual birth weights were available for only 8,504 cases. It has also been shown in the preceding sections that those cases for which actual birth weights are available selectively represent some socio-economic groups and do not represent the whole sample. Despite these limitations, three alternate models, similar to the previous models, have been developed with these 8,504 observations, and the results are given in the Appendix. With the exception of Model 1, the effect of cooking fuels, which is the main predictor variable in the analysis, on a baby's size at birth has declined substantially. In addition, the effects of maternal education, religion and caste, and geographic region have been found to be more pronounced in Model 2 and Model 3. This is possibly due to the over-representation of the children of high-income households, of educated mothers and of the southern and the western parts of the country in the reduced sample.

Discussion

It has been revealed from this study that using unprocessed biomass as cooking fuel significantly increases women's risk of delivering a small-sized baby, even after controlling for a number of potentially confounding variables such as child's sex, birth order and birth interval, mother's nutritional status, pregnancy care, maternal education, household standard of living. These results are consistent with the earlier studies of Guatemala (Boy et al. 2002) and Zimbabwe (Mishra et al. 2004) linking solid fuels to reduced birth weight, and provide further evidence that cooking with biomass can increase the risk of unfavourable birth outcomes.

In the absence of any other nationally representative data on birth weight in a developing country like India, the NFHS data provide a unique opportunity to study the relationship between biomass fuel use and a baby's size at birth, a proxy of birth weight, in the nationally representative sample. Moreover, data on a baby's size at birth and cooking fuel use are rarely available from the same source to allow such analyses. Earlier studies in India (e.g., Mavalankar et al. 1991) were based on small sample sizes, and generalization of the obtained results at the national or at least sub-national level was difficult. Nevertheless, several measurement constraints on perceiving a baby's size at birth should be kept in mind when considering the findings of this study. Also, exposure to indoor air pollution is measured here by the use of cooking fuel and does not reflect the actual exposure level as measured through a clinical procedure.

In addition to the type of cooking fuel and the demographic factors, such as sex of the baby, birth order and birth interval, a strong influence of other socio-economic factors in determining a baby's size at birth have also been found, particularly, the influence of maternal education, maternal nutrition and standard of living of the households are of immense importance. Utilization of antenatal care is also found to have some influence on a baby's size at birth, a finding that supports those of earlier studies (Herz and Measham 1987; Ebomoyi et al. 1991; Anandalakshmy et al. 1993; Gonzalez-Perez and Vega-Lopez 1996; Karim and Mascie-Taylor 1997). While the predominance of maternal nutritional indicators and utilization of antenatal care in determining a baby's size at birth has been revealed by most studies (Prazuck et al. 1993; Hollander 1997; Anderson and Bergstrom 1997; Das and Khanam; 1997; Magadi et al. 2001), many of these earlier studies have failed to detect such a significant association between socio-economic factors and poor birth outcomes in developing countries (Xu et al. 1995b; Bener et al. 1996; Peabody and Gertler 1997; Magadi et al. 2001). Regional differences in birth outcomes have also been observed in both bivariate and multivariate analyses, but the reason for those differences is not very clear. It may be due to region-specific cultural factors or to systematic misreporting of size of the sizes of babies by mothers of a certain socio-economic group. A detailed examination of regional-level cultural factors influencing pregnancy outcomes is called for, since these factors cannot be addressed with the available data and are thus beyond the scope of this study.

The results of this study suggest that significant variations in a baby's size at birth exist among different women after controlling for significant observed factors, implying that there may be unobserved or statistically unobservable personal characteristics of women that put some at higher risk of unfavourable birth outcomes than others. Such factors could include biological and genetic factors. It is equally important to acknowledge the fact that the size of a baby at birth may have been influenced by the differential reporting of mothers belonging to different socio-economic groups and may affect the values of the coefficients of other background characteristics to some extent in the regression analysis. On the other hand, some women may report a baby's size relative to the size of another, which would lead to an underestimation of the coefficients.

Conclusions

Recognizing the adverse health consequences of indoor air pollution among women during pregnancy (or otherwise) and also among children, widespread adoption of cleaner fuels would do the most to reduce the level of indoor air pollution. In India, however, poor households currently relying on biomass fuels are unlikely to switch to cleaner fuels soon on account of lack of affordability. It is in this sphere that government-sponsored intervention programs to improve public health in the country have to play a very important role. The intervention program should include: the creation of public awareness on a massive scale through education about the risks of exposure to cooking smoke; the promotion of economically viable cleaner fuels by changing the pattern of fuel use, such as use of *gobar* gas (gaseous fuel made from raw cow dung), subsidized schemes to facilitate switchover from biomass to LPG, use of solar energy; the provision of more efficient and better-ventilated cook stoves by modifying stove design via some mechanism (e.g., chimney) or putting a window above the cooking stove and providing cross-ventilation through the door in the existing houses. Inexpensive but highly-efficient cook stoves that use biomass fuels are an important part of an effective short-run strategy. The most successful cook stove program has been in China, where some 200 million improved stoves have been introduced in recent decades (Mishra et al. 2002). The Chinese program demonstrates that a concrete action with strong political will can achieve remarkable results. Although various programs have been launched in India to promote the use of improved stoves, they have not been widely accepted. Large-scale acceptance of improved stoves would require determined efforts and community participation, as it has been recognized that the most important barriers to new stove introduction are not technical but social (Gopalan and Saxena 1999). There is also a lack of evaluation studies on the effectiveness and efficiency of improved stoves. Effective tackling of indoor air pollution in India requires a multisectoral collaboration and commitment between agencies responsible for health, energy, environment, housing and rural development (Indian Council of Medical Research 2001).

In addition to the above interventions, there are other demographic and socio-economic covariates that are subject to intervention: maternal education and nutrition, household income, ensuring complete antenatal care to every expectant mother and so on. These factors are well-recognized for their strong positive influence on child health and survival (for detailed discussion see Ghosh 2005).

All the indicators of a baby's small size at birth addressed in the analyses vary significantly by region. Consequently, programs aimed at addressing these issues should be sensitive to regional disparities. There is need for qualitative studies to identify the unobserved behavioural and cultural factors contributing to a baby's small size at birth among various communities, especially at the regional level.

As mentioned earlier, information on smoke exposure was ascertained from type of fuel used for cooking and heating. Nevertheless, this research needs to be followed by carefully designed studies with better measures of smoke exposure and clinical measures of pregnancy outcomes including birth weight. Such research is important in light of the fact that a large proportion of households in India and other developing countries in Asia, as well as in Latin America, rely on biomass fuels for household energy and LBW is a known risk factor for childhood ill health and premature death.

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Endnotes

1 As information on household income or expenditure is not directly available, the standard of living index (calculated by NFHS-2) has been taken as the proxy for household economic status. The standard of living index consists of the following household and economic characteristics: type of house, toilet facility, source of lightning, main fuel for cooking, source of drinking water, use of separate room for cooking, ownership of house, ownership of agricultural land, ownership of irrigated land, ownership of livestock and ownership of durable goods. On the basis of the composite score related to these characteristics, the household standard of living has been divided into low, medium and high levels. The scale of standard of living ranges from 0 to 67 (0–14 for low, 15–24 for medium and 25–67 for high).

2 The variable complete antenatal care has been created by three separate variables. These are: (a) at least three antenatal checkups to any qualified medical or paramedic personal, (b) at least two doses of tetanus toxide injections and (c) receiving iron and folic acid tablets during pregnancy.

3 The geographic region variable has been created from NFHS data file: "north" includes Delhi, Haryana, Himachal Pradesh, Jammu and Kashmir, Punjab and Rajasthan; "central" includes Madhya Pradesh and Uttar Pradesh; "south" includes Andhra Pradesh, Karnataka, Kerala and Tamil Nadu; "west" includes Goa, Gujarat and Maharashtra; and "east & north-east" includes Bihar, Orissa and West Bengal, Arunachal Pradesh, Assam, Manipur, Meghalaya, Mizoram, Nagaland and Tripura.

4 Scheduled castes and scheduled tribes are castes and tribes identified by the Government of India as socially and economically disadvantageous sections of Indian society and in need of special protection from social injustice and exploitation.

Appendix

Predicted probability of LBW (<2,500 g) by type of cooking fuel and other selected background characteristics, India, NFHS-2, 1998–99

Predictors	Model 1	Model 2	Model 3
Type of cooking fuel			
Biomass fuels	23.3**	20.8	20.6
Cleaner fuels (ref.)	20.0	20.8	20.3
Sex			
Male (ref.)	20.1	19.4	18.9
Female	23.1**	22.4**	22.3**
Birth order/birth interval			
First birth (ref.)	22.1	21.7	21.4
Birth order 2–3/<24 months birth int.	25.3*	24.9*	24.7*
Birth order 2–3/≥24 months birth int.	19.5**	19.1*	18.9*
Birth order 4+/<24 months birth int.	27.8*	25.1	23.8
Birth order 4+/≥24 months birth int.	19.9	17.4*	15.9**
Mother's age			
<20		22.0	21.6
20–29 (ref.)		20.5	20.1
30+		20.9	20.5
Religion/caste			
Forward caste Hindu (ref.)		21.9	21.4
SC-ST Hindua		23.7	23.0
Other than Hindu		17.4**	17.5**
Maternal education			
Illiterate (ref.)		25.6	24.5
Primary-middle completed		21.8**	21.6*
Higher-educated		17.6**	17.4**
Standard of living			
Low		20.3	22.2
Medium (ref.)		20.9	21.4
High		20.8	18.5*

Mother's BMI			
<18.5 kg/m^2		24.1**	23.5**
≥18.5 kg/m^2 (ref.)		19.6	19.3
Complete antenatal care			
No (ref.)			20.4
Yes			20.4
Place of residence			
Rural (ref.)			20.8
Urban			20.1
Geographic region			
North (ref.)			28.4
Central			31.7**
South			15.4**
West			21.7**
East & North-east			19.3**
Number of births	**8,504**	**8,039**	**8,039**

Note: Adjusted probabilities are estimated by logistic regression. For any given predictor variable, the set of control variables consists of all other predictor variables shown in the table. When calculating adjusted percentages for categories of a given predictor variable, other variables are held constant at their mean values (for details, see Retherford and Choe 1993).
ref: Reference category
a- Scheduled castes and scheduled tribes
*p<.05, **p<.01