PN-ACK-106

EAST-WEST CENTER WORKING PAPERS

106791

EAST-WEST CENTER

Population Series

No. 92, October 1997

Effects of Cooking Smoke on Prevalence of Tuberculosis in India

Vinod Mishra, Robert D. Retherford, and Kirk R. Smith

Vinod Mishra is a Visiting Fellow and **Robert D. Retherford** is a Senior Fellow in the Program on Population at the East-West Center. **Kirk R. Smith** is a Senior Fellow in the Program on Environment at the East-West Center and a Professor in the School of Public Health at the University of California at Berkeley.

East-West Center Working Papers: Population Series are an unreviewed and unedited prepublication series reporting on research in progress. Please direct orders and requests to the East-West Center's Publication Sales Office. The price for Working Papers is $3.00 each plus postage. For surface mail, add $3.00 for the first title plus $0.75 for each additional title or copy sent in the same shipment. For airmail within the U.S. and its territories, add $4.00 for the first title plus $0.75 for each additional title or copy in the same shipment. For airmail elsewhere, add $7.00 for the first title plus $4.00 for each additional title or copy in the same shipment. Readers in developing countries may request single copies on a complimentary basis.

Established in 1969 as a unit of the East-West Center, the **Program on Population** conducts research and offers professional education focusing on population issues, with emphasis on the analysis of demographic and human-resource trends, their social and economic causes and consequences, and their policy implications in Asia, the Pacific, and the United States.

The Office of Population of the United States Agency for International Development (USAID) provided support for this publication under a cooperative agreement with the Program on Population of the East-West Center.

Address correspondence to: Dr. Vinod Mishra, Program on Population, East-West Center, 1601 East-West Road, Honolulu, HI 96848, USA; Tel: (1-808) 944-7452; Fax: (1-808) 944-7490; E-mail: mishra@hawaii.edu

A

The U.S. Congress established the East-West Center in 1960 to foster mutual understanding and cooperation among the governments and peoples of the Asia-Pacific region, including the United States. Principal funding for the Center comes from the U.S. government, with additional support provided by private agencies, individuals, and corporations, and more than 20 Asian and Pacific governments.

The Center promotes responsible development, long-term stability, and human dignity for all people in the region and helps prepare the United States for constructive involvement in Asia and the Pacific.

East-West Center Working Papers are circulated for comment and to inform interested colleagues about work in progress at the Center. Working Papers are issued in the following subseries: Economics and Politics Series, Education and Training Series, Energy and Minerals Series, Environment Series, and Population Series.

For more information about the Center or to order publications, contact:

Publication Sales Office
East-West Center
1777 East-West Road
Honolulu, Hawaii 96848

telephone: (808) 944-7145
facsimile: (808) 944-7376

EFFECTS OF COOKING SMOKE ON PREVALENCE OF TUBERCULOSIS IN INDIA

SUMMARY

Background: The effects of indoor air pollution on the risk of tuberculosis have not been studied previously. This study examines the effects of cooking smoke from biomass fuels on prevalence of tuberculosis among persons age 30 years and older in India.

Methods: The analysis is based on 173,520 persons age 30 and over in India's 1992–93 National Family Health Survey. Logistic regression was used to estimate the effects of cooking smoke from biomass fuels (wood or dung) on prevalence of active tuberculosis after controlling for a number of potentially confounding variables.

Results: Persons living in households that primarily use biomass for cooking fuel have a considerably higher prevalence of active tuberculosis than persons living in households that use cleaner fuels (OR 3.81; 95% CI 2.95-4.93). This effect is reduced somewhat when availability of a separate kitchen, house type, indoor crowding, age, gender, urban-rural residence, education, religion, caste/tribe, and geographic region are statistically controlled (OR 2.75; 95% CI 2.07-3.67). Cooking smoke also has a large effect when the analysis is done separately for men (OR 2.59; 95% CI 1.84-3.64) and women (OR 3.06; 95% CI 2.00-4.67) and separately for urban areas (OR 2.47; 95% CI 1.70-3.58) and rural areas (OR 2.76; 95% CI 1.79-4.26). The analysis also indicates that, among persons age 30 years and older in India as a whole, 53 percent of the prevalence of active tuberculosis is attributable to cooking smoke.

Conclusion: Results strongly suggest that use of biomass fuels for cooking substantially increases the risk of tuberculosis in India.

Key words: cooking smoke, indoor air pollution, biomass, health, tuberculosis, TB, India.

BACKGROUND

Air pollution is commonly perceived as an urban problem associated with motor vehicles and industries. In developing countries, however, air pollution tends to be highest indoors, where biomass fuels such as wood, animal dung, crop residues, and grasses are burned by many households for cooking and space heating.[1] Biomass fuels are at the high end of the fuel ladder in terms of pollution emissions, and at the low end in terms of combustion efficiency.[2] Biomass smoke contains many noxious components, including respirable suspended particulates, carbon monoxide, nitrogen oxides, formaldehyde, and polyaromatic hydrocarbons such as benzo(a)pyrene. High exposures to these air pollutants can cause serious health problems.[3,4,5] It has been estimated, for example, that indoor air pollution in developing countries accounts for 2.2–2.5 million deaths annually.[6]

According to India's 1992–93 National Family Health Survey (NFHS), about three-quarters of households use unprocessed biomass as their primary fuel for cooking food. Among households that use biomass fuels, more than 90% report using wood or animal dung as their primary cooking fuel.[7] Cooking areas in many Indian households tend to be poorly ventilated, and about one-half of all households do not have a separate kitchen.[7] To a considerable extent, life revolves around the cooking area, and women spend much of their time there. Cooking stoves in most households are simple—often just a pit, a *chulha* (a U-shaped construction made from mud), or three pieces of brick. Under these conditions, household members, especially women, tend to have high levels of exposure to cooking smoke. In developing countries such as India, daily air pollution exposures from cooking with biomass typically exceed relevant health-based guidelines by factors of 20 or more.[2]

Tuberculosis is a major health problem in India. According to a recent World Health Organization report on tuberculosis, India has the largest pool of people infected with *Mycobacterium tuberculosis* (tubercle bacillus) of any nation.[8] It is estimated that more than half of India's adult population are infected with the tuberculosis bacterium.[8] Typically 5–10% of those infected eventually become ill with active tuberculosis.[9] However, this percentage may be higher in the case of India, because of the ubiquity of the tuberculosis bacillus, high population density, and poor socioeconomic and health conditions. Tuberculosis accounts for nearly 5% of the national burden of disease in India, more than in any other major world region.[10] Approximately 500,000 persons die from tuberculosis each year in India.[8] In recent years, the growth of drug-resistant tuberculosis and the rapid spread of HIV/AIDS have contributed to the resurgence of tuberculosis in India and in other parts of the world.[11,12,13,14,15]

The NFHS recorded an overall active tuberculosis prevalence rate of 467 per 100,000 persons[7]—slightly higher than other estimates of the active (sputum-positive) disease rate in India, which mostly range between 400 and 450 per 100,000 persons.[14]

We are not aware of any previous studies of the effects of cooking smoke on tuberculosis. For some other respiratory diseases, however, cooking smoke is a known risk factor. For example, cooking smoke has been shown to increase the risk of acute respiratory infections,[16,17,18,19,20] chronic obstructive lung disease,[21,22,23,24] cor pulmonale,[25,26] and lung cancer.[27,28] There is related evidence that smoke from cigarettes, which are also a form of biomass, is a risk factor for pulmonary tuberculosis,[29,30,31,32,33] and that cigarette smoking renders the treatment of tuberculosis less effective.[31,34] Moreover, passive cigarette smoke has been shown to increase the risk of pulmonary tuberculosis in children.[35] Outdoor air pollution has also been shown to be correlated with tuberculosis. For example, a study in Shenyang, China, found that the prevalence of tuberculosis was about five times greater in high-pollution areas than in low-pollution areas after controlling for age, cigarette smoking, and indoor air pollution.[36] However, this study did not control for socioeconomic factors.

It is plausible that cooking smoke increases the risk of tuberculosis by compromising the respiratory system's ability to resist infection by *Mycobacterium tuberculosis* or to resist development of active tuberculosis in already infected persons. This is all the more likely in India, where tuberculosis is comparatively common and where it is difficult to avoid coming into contact with persons who harbor the disease. Moreover, treatments of chronic respiratory diseases brought on by cooking smoke often include immunosuppressive drugs, such as bronchodilators and corticosteroids, which are known to predispose to reactivation of tuberculosis.[37]

In sum, there seems to be no direct evidence that cooking smoke increases the risk of tuberculosis. What little indirect evidence there is comes mainly from studies of the effects of cigarette smoking, which tend to produce higher exposures to pollutants than does cooking smoke (depending, of course, on how much the person smokes). Passive cigarette smoke and outdoor air pollution, which tend to produce lower exposures to pollutants than cooking smoke, have also been linked to increased risk of tuberculosis.

This study examines the relationship between biomass fuels for cooking and the prevalence of active tuberculosis among persons age 30 years and older in India, after statistically controlling for the effects of several potentially confounding variables. The analysis is limited primarily to persons age 30 years and older because in India tuberculosis prevalence rates are much higher among persons age 30 and older than among persons below age 30, and also because the effects of cooking smoke on the risk of active tuberculosis may be long-term and cumulative. To the best of our knowledge, this is the first study to provide evidence of a link between cooking smoke and tuberculosis.

METHODS

India's National Family Health Survey (NFHS), conducted during 1992–93, provided data for this study. The NFHS collected socioeconomic, demographic, and health information from a nationally representative probability sample of 88,562 households, including 514,827 persons within those households. Details of the NFHS sampling design are found in the basic survey report.[7] For reasons already described, the analysis is restricted mainly to persons age 30 years and older, who number 173,520 in the NFHS sample.

The NFHS asked several questions relating to the current health status of household members, including whether each member suffered from active tuberculosis. The question was (referring to the listing of persons in the household), "Does anyone listed suffer from tuberculosis?" The household head or other knowledgeable adult in the household reported for the entire household. No effort was made to clinically test for the disease. In our analysis this reported prevalence of active tuberculosis is the response variable, which is represented by a dummy variable with value 1 if a person suffers from active tuberculosis and 0 otherwise.

Cooking smoke, measured indirectly by type of cooking fuel, is the primary explanatory variable. The NFHS used a nine-fold classification of cooking fuel—wood, dung, charcoal,

coal/coke/lignite, kerosene, electricity, liquefied petroleum gas, bio-gas, and a residual category of other fuels. The question was, "What type of fuel does your household mainly use for cooking?" which was followed by the above list of fuels. In our analysis, we have grouped these various cooking fuels into two categories—biomass fuels (wood or dung) and cleaner fuels (charcoal, coal/coke/lignite, kerosene, electricity, petroleum gas, or bio-gas). The residual category of other fuels, used by only about two percent of the sample, is excluded from the analysis due to the mixed nature of fuels in that category. Type of cooking fuel is represented by a dummy variable with value 1 for biomass fuels and 0 for cleaner fuels.

The NFHS did not include a separate category for crop residues, which are known to be an important source of fuel for cooking in India.[38] Evidently, most households using crop residues as their primary cooking fuel reported using wood, inasmuch as the proportion of households falling in the residual category of other fuels is only 2 percent.

Coal/coke/lignite can also be highly polluting, but we classify them here as cleaner fuels in terms of exposure to cooking smoke. We do this because most smoke from these fuels is produced within the first few minutes after the fire is started. Moreover, in India, these fuels are usually burned on portable stoves that are often started in open areas and then, when the fire is burning more cleanly, brought indoors for cooking. Biomass fuels, on the other hand, are usually burned on non-portable stoves and require regular fuel-feeding, resulting in continuous release of considerable amounts of smoke.

Because the effects of cooking smoke (from biomass fuels relative to cleaner fuels) on tuberculosis are likely to be confounded with the effects of other risk factors, it is necessary to statistically control, or adjust, for such factors. Control variables included in this study are: availability of a separate kitchen in the house, housing type (indicating quality of construction of roof, walls, and floor), indoor crowding (measured by number of persons per room in the household), age, gender, urban-rural residence, education, religion, caste/tribe, and geographic region. The rationale for including these variables as controls is discussed below.

Availability of a separate kitchen is included because it controls to some extent for exposure to cooking smoke and also for household economic status. It is important to control for household economic status because it is an indirect indicator of not only nutrition and health but also access to medical services that might prevent or cure active tuberculosis. The NFHS did not collect income data, so we have no direct measure of household income. Housing type is included because it is also correlated with household economic status and may also control to some extent for ventilation in the house. Housing type is dichotomized into *kachcha* (made from mud, thatch, or other low-quality construction materials throughout) and *pucca* or semi-*pucca* (made from at least some high-quality construction materials such as bricks, tiles, cement, or concrete). Average number of persons per room in the household controls for indoor crowding, which may also be correlated with exposure to cooking smoke as well as household economic status, unhygienic conditions, and exposure to infection.

Age is included because it has a large effect on the risk of tuberculosis and because intensity of exposure to cooking smoke may vary somewhat with age. (However, the correlation between use of biomass fuels and age is only .049 in our data -- .038 for urban and .016 for rural.) Gender is included mainly because women do the cooking and are therefore exposed more intensely to cooking smoke than men are. Urban-rural residence is included because it is correlated with type of cooking fuel, household economic status, and access to and use of medical services which may prevent or cure tuberculosis. Education is included because it is also correlated with access to and use of medical services, as well as cooking fuel type and economic status. Religion and caste/tribe are included because they may capture cultural and life style differences that are correlated with type of cooking fuel, cooking practices, and intensity of exposure to cooking smoke. Geographic region is included to control for regional differences in climate, topography, and local customs that may be correlated with both tuberculosis and exposure to cooking smoke.

All of our variables are categorical and are represented by dummy variables in the analysis. All variables except age, education, religion, and region are dichotomous. Age is grouped into five categories—30–39, 40–49, 50–59, 60–69, and 70 years or older—represented by four dummy variables, with 30–39 as the reference category. Education has three categories which are represented by two dummy variables—one for medium education (literate but less than high school) and one for high education (high school or more), with illiterate as the reference category. Religion also has three categories which are represented by two dummy variables—one for Hindu and one for "other religion (Sikh, Buddhist, Christian, Jain, Jewish, Zoroastrian, etc.)," with Muslim as the reference category.

Geographic region is represented by three dummy variables—one for north and northeast (including Jammu Region of Jammu & Kashmir, Himachal Pradesh, Assam, Arunachal Pradesh, Manipur, Meghalaya, Mizoram, Nagaland, and Tripura), one for central and eastern (including Haryana, Punjab, National Capital Territory of Delhi, Uttar Pradesh, Madhya Pradesh, Bihar, West Bengal, and Orissa), and one for west (including Maharashtra, Goa, Gujarat, and Rajasthan), with south (including Andhra Pradesh, Karnataka, Kerala, and Tamil Nadu) as the reference category.

Because our response variable—tuberculosis—is categorical, logistic regression is used to estimate the effects of cooking fuel type, which is our principal predictor variable, with the ten demographic and socioeconomic variables mentioned earlier as controls. Results are presented mostly in the form of odds ratios with 95% confidence intervals. The estimation of confidence intervals and significance levels takes into account design effects due to clustering at the level of the primary sampling unit. The logistic regression models were estimated using the SVYLOGIT option in the STATA statistical software package.[39]

In the NFHS, certain states and certain categories of households were oversampled. In all our analysis, weights are used to restore the representativeness of the sample.[7]

RESULTS

Table 1 contains a list of variables and their mean values in our sample of 173,520 persons age 30 and over. Mean values are presented separately for urban, rural, and total (i.e., urban and rural combined). The table shows that overall prevalence of active tuberculosis is in the neighborhood of 1%. Prevalence of tuberculosis is almost twice as high in rural areas as in urban areas. Biomass fuels are used for cooking by about three-quarters of the population. By residence, the proportion using biomass fuels is almost three times higher in rural areas (93%) than in urban areas (32%). The means of the control variables relating to housing, education, and caste/tribe also differ considerably between urban and rural areas.

Effects of cooking fuel type on tuberculosis

Figure 1 shows the effects of cooking fuel type on prevalence of tuberculosis. The unadjusted and adjusted prevalence rates shown in this figure are predicted values derived by logistic regression and multiple classification analysis, which is a method for transforming regression results into simple bivariate tables which can be depicted as bar graphs.[40] The unadjusted prevalence rates are predicted from a logistic regression of tuberculosis (1 if suffering from active tuberculosis, 0 otherwise) on type of cooking fuel (1 if wood or dung, 0 otherwise). The adjusted prevalence rates are predicted from a logistic regression of tuberculosis on type of cooking fuel and the ten control variables discussed earlier. In the calculation of adjusted prevalence rates, the control variables are held constant by setting them to their mean values in the underlying logistic regression. In the calculation of both unadjusted and adjusted prevalence rates, the value of the constant term in each underlying logistic regression is reset so that, with the predictor variable or variables set to their mean values, the prevalence rate predicted by the regression equals the observed prevalence rate.

Figure 1 shows that the unadjusted prevalence rate of tuberculosis is about four times higher among persons living in households using biomass fuels than among persons living in households using cleaner cooking fuels. The adjusted rate is somewhat less than three times higher—1,271 (per 100,000) among those using biomass fuels and 465 among those using cleaner fuels. The difference in the adjusted prevalence rates of tuberculosis between biomass-fuel users and cleaner-fuel users is large and highly statistically significant (p<.0001).

The unadjusted and adjusted effects of cooking smoke in Figure 1 may also be expressed as odds ratios as shown in Table 2, which is discussed in more detail in the next section. The first line of this table shows that the unadjusted odds ratio is 3.81 (95% CI 2.95-4.93) and the adjusted odds ratio is 2.75 (95% CI 2.07-3.67).

Because the tuberculosis prevalence rate in our sample increases rapidly after age 20, it is also of interest to examine the effects of cooking smoke on the prevalence of tuberculosis among persons age 20 years and older. With the lower cutoff, the unadjusted odds ratio is 3.56 (95% CI 2.82-4.50) and the adjusted odds ratio is 2.58 (95% CI 1.98-3.37). Both the unadjusted and adjusted odds ratios with cutoff at age 20 are only slightly lower than the unadjusted and adjusted odds ratios with cutoff at age 30, indicating that the effects of cooking smoke on the prevalence of tuberculosis are fairly robust to choice of a cutoff age. Effects of the control variables also hardly change when the cutoff age is lowered to 20.

Effects of the control variables on tuberculosis

The effects of the control variables on prevalence of tuberculosis, which are also shown in Table 2, are also of interest. In this table, as already mentioned, effects are expressed as odds ratios. The entries in the unadjusted column in Table 2 are based on eleven separate logistic regressions, one for each predictor variable indicated in the row labels. Each such regression contains only one predictor variable. The entries in the adjusted column are based on a single logistic regression that contains all eleven predictor variables. In the adjusted column, the composition of the control variables changes as one moves down the column. For a column entry corresponding to a particular predictor variable specified by a row label, the set of control variables consists of all the other predictor variables in the table. The discussion below focuses on the adjusted effects of the control variables.

With other variables controlled, persons living in households with a separate kitchen have a considerably lower risk of tuberculosis than persons living in households without a separate kitchen, as expected. Also as expected, persons living in higher quality housing (*pucca* or semi-*pucca*) have a somewhat lower risk of tuberculosis, but the effect is not statistically significant. Surprisingly, crowding within the house does not show any significant effect on the prevalence of tuberculosis. Older persons have a considerably higher prevalence, as expected.

Despite higher exposures to cooking smoke, women have a much lower prevalence of tuberculosis than men. One likely reason is that in India men are more likely than women to come in contact with people who suffer from active tuberculosis. Another likely reason is that men tend to smoke and drink more than women. Although our inability to control for tobacco smoking and alcohol consumption may bias the effect of gender on prevalence of tuberculosis, it is unlikely to bias the effect of cooking smoke, because there is no reason to believe that tobacco smoking and alcohol consumption are significantly correlated with cooking fuel type in India.

With other variables controlled, urban residents have a higher prevalence of tuberculosis than rural residents. This effect, which is not statistically significant, is the reverse of what is found for unadjusted prevalence, which is considerably lower in urban areas. It may be that after cooking fuel type and other socioeconomic and demographic variables are controlled, the reversal in the direction of the effect of urban residence reflects higher levels of population density and higher levels of outdoor pollution in urban areas.

More educated persons have a considerably lower prevalence of tuberculosis, as expected. Muslims have a higher prevalence of tuberculosis than either Hindus or persons in the residual category of other religions. A higher prevalence of tuberculosis among Muslims may occur because of poorer access to and use of medical services. Persons who belong to scheduled castes and scheduled tribes (groups that are officially recognized as underprivileged) have a somewhat higher prevalence of tuberculosis than persons who belong to other castes, perhaps mainly because persons from scheduled castes and scheduled tribes have poorer access to medical care. The difference is not statistically significant, however.

The prevalence of tuberculosis is highest in the north and northeast region, followed by the central and eastern region, the west region, and the south region. The regional differentials indicate a geographical gradient in the prevalence of tuberculosis that tends to fall from north to south. Reasons for this north-south gradient are unclear but may be related to climatic differences.

Further analysis of gender differences and urban-rural differences in the prevalence of tuberculosis

Because women tend to do the cooking and are much more exposed than men to cooking smoke, and because urban and rural environments are so different, we decided to repeat the above analysis separately for men and women and separately for urban areas and rural areas. Only adjusted effects are discussed.

Figure 2 shows adjusted prevalence of tuberculosis by type of cooking fuel separately for men and women. The methodology for estimating the adjusted prevalence levels in this figure is similar to that in Figure 1, discussed earlier. In the case of the two bars for males in Figure 2, the control variables are set to their mean values for males, and in the case of the two bars for females, the control variables are set to their mean values for females. In this figure the adjusted effect of biomass fuels, relative to cleaner fuels, on the prevalence of tuberculosis is large and highly statistically significant for both men and women ($p<.0001$ in each case). The adjusted effect is considerably larger for women than for men. This is consistent with expectation, because women are more exposed than men to cooking smoke. However, given the relatively low status of women in India, tuberculosis may be less likely to be reported for women than for men, especially in households that use biomass fuels for cooking. For this reason, the gender differential in the effect of cooking smoke on prevalence of tuberculosis may be greater than indicated by our analysis.

It is noteworthy that only 3% of Indian women smoke tobacco.[41] Therefore, tobacco smoking, about which the NFHS has no information, cannot be an important confounding factor when the analysis is done separately for women in Figure 2. Even in the case of men, tobacco smoking is probably not a confounding factor, because, as mentioned earlier, it is unlikely to be correlated with exposure to cooking smoke.

Table 3 provides additional detail on adjusted effects of the control variables on the prevalence of tuberculosis by gender, as measured by odds ratios. The effects of the control variables tend to be rather similar among men and women, except that age has a considerably larger effect among men than among women, for reasons that are unclear.

Figure 3 shows adjusted prevalence of tuberculosis by type of cooking fuel separately for urban areas and rural areas. In the case of the two urban bars the control variables are set to their mean values in urban areas, and in the case of the two rural bars the control variables are set to their mean values in rural areas. In Figure 3, the adjusted effect of biomass fuels relative to cleaner fuels on the prevalence of tuberculosis is large and highly statistically significant for both urban areas and rural areas ($p<.0001$ in each case). The adjusted effect is somewhat larger in rural areas than in urban areas. The smaller effect in urban areas probably occurs mainly because the availability and quality of medical services for prevention and treatment of tuberculosis is better in urban areas.

The adjusted effects of the control variables on the prevalence of tuberculosis by urban-rural residence are presented in Table 4. The effects of the control variables tend to be rather similar in urban areas and rural areas, except that the effect of education is larger in urban areas than in rural areas.

Proportion of tuberculosis prevalence attributable to cooking smoke

It is also of interest to consider the proportion of tuberculosis prevalence in the population that is attributable to smoke from biomass fuels, relative to cleaner fuels. The commonly used "population attributable risk proportion" is defined in terms of incidence,[42] but our data pertain to prevalence. Therefore, we analogously define a "population attributable prevalence proportion" as

$$\frac{\text{(Prevalence in total population) - (Prevalence in unexposed group)}}{\text{(Prevalence in total population)}}$$

This measure can be interpreted as the proportionate reduction in prevalence of tuberculosis in the population that would occur if, hypothetically, everyone were to use cleaner fuels. Those using cleaner fuels are the unexposed group in the formula. If everyone uses cleaner fuels, the mean values of the other predictor variables in the unexposed group must be the same as the mean values of the predictor variables in the total population. Therefore, adjusted values of prevalence, with control variables set to their mean values in the total population, must be used to estimate "prevalence in unexposed group" in the formula. Logistic regression is again used to estimate these adjusted values. If the calculation of population attributable prevalence proportion is done separately for urban areas and rural areas, "total population" in the formula then refers to "total urban population" or " total rural population."

Applying this formula, we find that 53 percent of the prevalence of active tuberculosis among persons age 30 years and older is attributable to cooking smoke from biomass fuels. This proportion is 25 percent in urban areas and 61 percent in rural areas. The proportion is much higher in rural areas not only because the effect of biomass fuels on tuberculosis is higher in rural areas, but also because the proportion of households using biomass fuels is much higher in rural areas.

CONCLUSIONS

Results from this study strongly suggest that exposure to cooking smoke (from biomass fuels compared with cleaner fuels) substantially increases the risk of active tuberculosis among persons age 30 years and older in India. This is true even when the effects of a number of potentially confounding variables are statistically controlled by holding them constant. The adjusted effect of cooking fuel type on the prevalence of tuberculosis is large (OR=2.75) and highly statistically significant (p<.0001). Effects are also large and highly statistically significant when the analysis is done separately for men (OR=2.59) and women (OR=3.06) and separately for urban areas (OR=2.47) and rural areas (OR=2.76). Lowering the cutoff age to 20 years slightly reduces these effects.

The true effects of cooking smoke on tuberculosis may be stronger than we have estimated, for the following reasons. The first reason is that households in India typically use a combination of cooking fuels, whereas we have information only on the primary cooking fuel. Our estimated effects are attenuated to the extent that a mix of biomass fuels and cleaner fuels is actually used by many households instead of biomass fuels alone. The second reason stems from our lack of information about the history of fuel use in the household, which is important because the effects of cooking smoke on the risk of tuberculosis are likely to be cumulative over time. This implies that previous shifts from biomass fuels to cleaner fuels tend to bias downwardly our estimates of effects. Our estimated effects of cooking smoke from biomass fuels on tuberculosis would also be larger had we measured the effects of biomass fuels relative to a very clean fuel such as electricity instead of a residual category of other fuels that includes charcoal, coal/coke/lignite, kerosene, petroleum gas, and bio-gas as well as electricity. Finally, there is also a possibility of underreporting of tuberculosis in the NFHS due to the stigma attached to the disease[7] and, in some cases, to lack of awareness that one has the disease. Underreporting for these reasons may be greater among persons living in households using biomass fuels and among women. This differential underreporting, to the extent that it occurs, would contribute to underestimation of the effect of cooking smoke on the prevalence of tuberculosis and to underestimation of the gender differential in the effect of cooking smoke on prevalence of tuberculosis.

There are several factors that could affect the validity of our conclusions. Fuel type is not an ideal measure of exposure to smoke, and reports of tuberculosis by household heads or other household informants are not as accurate as clinical measures of active tuberculosis. And although our set of control variables includes several measures of socioeconomic status, which is correlated with access to and use of medical services, we were not able to control directly for extent of use of medical services in connection with tuberculosis, because the NFHS did not collect any information on this subject. The NFHS also did not collect any data on nutritional status of respondents or data on such behaviors as tobacco smoking, drinking, and exposure to hazardous conditions at work which might account for some of the variation in prevalence of tuberculosis. Moreover, the NFHS did not cover institutionalized persons, and it contains no information on persons who have been treated and cured of tuberculosis. If such persons are disproportionately from households that use cleaner fuels, their omission from our data would produce an upward bias in our estimated effects of cooking smoke on tuberculosis.

The socioeconomic variables included as controls in our models are likely to capture much, but not all, of the effects of these missing variables on tuberculosis. Moreover, tobacco smoking and alcohol consumption are confounders only to the extent that they are correlated with cooking fuel type, and this correlation is probably small. Future health surveys should nonetheless consider including additional questions on these variables. Longitudinal intervention studies using epidemiological methods would be especially useful for untangling the effects of the various risk factors of tuberculosis, although cross-sectional surveys such as the NFHS are also very useful because they typically cover much larger and more representative populations at a considerably lower cost per respondent.

Our findings suggest that the prevalence of tuberculosis in India, and probably in many other developing countries as well, could be reduced substantially by lowering exposure to cooking smoke from biomass fuels. Perhaps the most obvious long-run policy implication is that the government should promote a shift from biomass fuels to cleaner fuels, which would also have significant health benefits from reduced ophthalmic, respiratory, cardiovascular, and perinatal problems. In the short run, however, such a shift may not be feasible for the large proportion of households who cannot afford more expensive cleaner fuels. Moreover, given current infrastructure and fuel availability, neither the Indian government nor the private sector is in a position to provide all households with cleaner fuels. A more feasible policy in the short run would be for the government to increase its efforts to educate the public about the adverse health effects of cooking smoke and to accelerate its improved cookstove program by making available inexpensive biomass-burning stoves that are fuel-efficient, less smoky, and equipped with flues or hoods designed to prevent the release of pollutants directly into the kitchen and other parts of the dwelling. For such programs to be effective, local needs and community participation should be given high priority. The government should also continue to strengthen its tuberculosis prevention and treatment programs.

ACKNOWLEDGMENTS

We are grateful to Robert S. Chapman, Markus Faigle, Thomas Frieden, Fabio Luelmo, Norman Y. Luther, Premlata Menon, F. DeWolfe Miller, Mark Nicas, Lee Reichman, and Sergio Spinaci for helpful comments, and to the United States Agency for International Development for funding this research.

REFERENCES

1. Smith KR. Indoor Air Pollution in India. *Natl Med J India.* 1996; 9(3): 103–4.
2. Smith KR, Liu Y. Indoor Air Pollution in Developing Countries. *Epidemiol Lung Cancer.* 1994; 74: 151–84.
3. WHO (World Health Organization). *Epidemiological, Social, and Technical Aspects of Indoor Air Pollution from Biomass Fuel: Report of a WHO Consultation June 1991.* Geneva: World Health Organization, 1992.
4. Smith KR. *Biofuels, Air Pollution, and Health: A Global Review.* New York: Plenum Press, 1987.
5. Smith KR. Fuel Combustion, Air Pollution Exposure, and Health: The Situation in Developing Countries. *Ann Rev Energy and Env.* 1993; 18: 529–66.
6. WHO (World Health Organization). *Health and Environment for Sustainable Development.* Geneva: World Health Organization, 1997.
7. IIPS (International Institute for Population Sciences). *National Family Health Survey (MCH and Family Planning): India 1992–93.* Bombay: International Institute for Population Sciences, 1995.
8. WHO (World Health Organization). *WHO Report on the Tuberculosis Epidemic 1997.* Geneva: World Health Organization, 1997.
9. American Thoracic Society/Center for Disease Control. Diagnostic Standards and Classification of Tuberculosis. *Am Rev Respir Dis.* 1990; 142: 725–35.
10. Murray CJL, Lopez AD, eds. *Global Burden of Disease.* Cambridge, MA: Harvard University Press, 1996.
11. Raviglione MC, Snider DE, Kochi A. Global Epidemiology of Tuberculosis: Morbidity and Mortality of a Worldwide Epidemic. *JAMA.* 1995; 273(3): 220–6.
12. Piot P. Tuberculosis and AIDS: The Dual Epidemic. *UNAIDS: Points of View.* 1997.
13. Kochi A. Tuberculosis: Distribution, Risk Factors, Mortality. *Immunobiol.* 1994; 191: 325–36.
14. WHO (World Health Organization). *Tuberculosis Programme Review: India.* Geneva: World Health Organization, 1992.
15. Sawert H. The Re-Emergence of Tuberculosis and its Economic Implications. *PharmacoEconomics.* 1996; 9(5): 379–81.
16. Mishra V, Retherford RD. Cooking Smoke Increases the Risk of Acute Respiratory Infection in Children. *National Family Health Survey Bulletin.* 1997; 8: 1–4.
17. Kossove D. Smoke-Filled Rooms and Lower Respiratory Disease in Infants. *S Afr Med J.* 1982; 63: 622–4.

18. Pandey MR, Boleji J, Smith KR, Wafula E. Indoor Air Pollution in Developing Countries and Acute Respiratory Infection in Children. *Lancet.* 1989; 25(February): 427–9.

19. Collings DA, Sithole SD, Martin KS. Indoor Woodsmoke Pollution Causing Lower Respiratory Disease in Children. *Trop Doct.* 1990; 20(October): 151–5.

20. Armstrong JRM, Campbell H. Indoor Air Pollution Exposure and Lower Respiratory Infection in Young Gambian Children. *Int J Epidemiol.* 1991; 20(2): 424–8.

21. Malik SK. Exposure to Domestic Cooking Fuels and Chronic Bronchitis. *Indian J Chest Dis Allied Sci.* 1985; 27: 171–4.

22. Pandey MR. Domestic Smoke Pollution and Chronic Bronchitis in a Rural Community of the Hill Region of Nepal. *Thorax.* 1984; 39: 337–9.

23. Behera D, Jindal SK. Respiratory Symptoms in Indian Women Using Domestic Cooking Fuels. *Chest.* 1991; 100(2): 385–8.

24. Perez-Padilla R, Regalado J, Vedal S, et al. Exposure to Biomass Smoke and Chronic Airway Disease in Maxican Women: A Case-control Study. *Am J Respir Crit Care Med.* 1996; 154(3 Pt 1): 701–6.

25. Pandey, M. R. et al. *Chronic Bronchitis and Cor Pulmonale in Nepal.* Kathmandu, Nepal: Mrigendra Medical Trust, 1988.

26. Padmavati S, Arora SS. Sex Differences in Chronic Cor Pulmonale in Delhi. *Br J Dis Chest.* 1976; 70: 251–9.

27. Sobue T. Association of Indoor Air Pollution and Lifestyle with Lung Cancer in Osaka, Japan. *Int J Epidemiol.* 1990; 19(Supplement 1): s62–s66.

28. Sun XW. Heating Fuels and Respiratory Diseases in the Risks of Female Lung Cancer. *Chung Hua Chung Liu Tsa Chih.* 1992; 13(6): 413–5. (abstract only)

29. Alcaide J, Altet MN, Plans P, et al. Cigarette Smoking as a Risk Factor for Tuberculosis in Young Adults: A Case-control Study. *Tuber Lung Dis.* 1996; 77(2): 112–6.

30. Ionescu J, Galbenu P, Lutescu L. Influence of Tobacco Smoking on the Development of Experimental Pulmonary Tuberculosis. *Rev Ig Bacteriol Virusol Parazitol Epidemiol Pneumoftiziol.* 1976; 25(4): 237–44. (abstract only)

31. Shprykov AS, Zhadnov VZ. Effects of Tobacco Smoking on the Course of Infiltrative Pulmonary Tuberculosis and Effectiveness of its Treatment. *Probl Tuberk.* 1994; 5: 26–7. (abstract only)

32. Mihaltan F, Defta D, Tabacu E. A Profile of the Smoker with Pulmonary Tuberculosis. *Pneumoftiziologia.* 1995; 44(1–2): 33–6. (abstract only)

33. Yu GP, Hsieh CC, Peng J. Risk Factors Associated with the Prevalence of Pulmonary Tuberculosis among Sanitary Workers in Shanghai. *Tubercle.* 1988; 69(2): 105–12.

34. Parrella M, Leo R, Liccardo M, Altieri V. Negative Effects of Cigarette Smoking on Chemo-antibiotic Therapy in Patients with Pulmonary Tuberculosis. *Arch Monaldi.* 1980; 35(5–6): 313–26. (abstract only)

35. Altet MN, Alcaide J, Plans P, et al. Passive Smoking and Risk of Pulmonary Tuberculosis in Children Immediately Following Infection: A Case-control Study. *Tuber Lung Dis*. 1996; 77: 537–44.

36. Xu Z, Chen B-H, Kjellstrom T, Xu X, Lin Y, Daqian Y. Study of Severe Air Pollution and Mortality in Shenyang, China. *Air Pollution & its Health Effects in China*. Geneva: World Health Organization, 1995: 47–88.

37. Singh S, Singh N, Razvi SK. Tuberculosis Following Immunosuppressive Treatment After Exposure to Toxic Smoke. *Lancet*. 1995; 345: 1379–80.

38. Ravindranath NH, Hall DO. *Biomass, Energy, and Environment: A Developing Country Perspective from India*. Oxford University Press, 1995.

39. Stata Corporation. *Stata Reference Manual, Release 5, Volume P-Z*. College Station, Texas: Stata Press, 1997.

40. Retherford RD, Choe MK. *Statistical Models for Causal Analysis*. New York: John Wiley & Sons, Inc., 1993.

41. WHO (World Health Organization). *Tobacco or Health: A Global Status Report*. Geneva: World Health Organization, 1997: 414–7.

42. Mausner JS, Kramer S. *Epidemiology: An Introductory Text*. Philadelphia: W.B. Saunders Company, 1985.

Table 1: Variable definitions and mean values[1] for persons age 30 years and older, India 1992–93

Variable name	Variable definition	Means Urban	Rural	Total
	Response variable (mean values expressed per 100,000)			
TB	Dummy variable, with value 1 if person suffers from active tuberculosis	611	1165	1011
	Predictor variables (mean values of dummy variables expressed as percentages)			
BIOMASS	Dummy variable, with value 1 if person lives in a household that uses wood or animal dung as its primary cooking fuel	32.1	93.1	75.8
KITCHEN	Dummy variable, with value 1 if person lives in household that has separate kitchen	67.9	54.1	57.9
PUCCA	Dummy variable, with value 1 if person lives in a pucca (high quality) or semi-pucca house[2]	84.1	41.8	53.6
CROWD	Dummy variable, with value 1 if three or more persons per room in the household	38.7	45.6	43.7
AGE40_49	Dummy variable, with value 1 if age 40–49	26.2	23.8	24.5
AGE50_59	Dummy variable, with value 1 if age 50–59	17.4	17.8	17.7
AGE60_69	Dummy variable, with value 1 if age 60–69	11.6	14.7	13.9
AGE70+	Dummy variable, with value 1 if age 70 years or older	6.8	8.7	8.2
FEMALE	Dummy variable, with value 1 if female	47.2	48.1	47.9
URBAN	Dummy variable, with value 1 if residence is urban	100.0	0.0	27.8
EDM	Dummy variable, with value 1 for literate people with less than a high school education	34.3	26.7	28.8
EDH	Dummy variable, with value 1 for people with at least a high school education	33.7	8.7	15.6
HINDU	Dummy variable, with value 1 if the person lives in a household whose head is Hindu	76.8	84.8	82.6
OTHREL	Dummy variable, with value 1 if the person lives in a household whose head is not Hindu or Muslim	8.0	5.7	6.3

(Table 1 continued)

Variable name	Variable definition	Means		
		Urban	Rural	Total
SCST	Dummy variable, with value 1 if the person lives in a household whose head belongs to a scheduled caste (SC) or scheduled tribe (ST)[3]	11.4	23.6	20.2
NORTH	Dummy variable, with value 1 for people living in Jammu Region of Jammu & Kashmir, Himachal Pradesh, Assam, Arunachal Pradesh, Manipur, Meghalaya, Mizoram, Nagaland, or Tripura	2.6	5.0	4.4
CENTR	Dummy variable, with value 1 for people living in Haryana, Punjab, Delhi, Uttar Pradesh, Madhya Pradesh, Bihar, West Bengal, or Orissa	47.1	55.1	52.9
WEST	Dummy variable, with value 1 for people living in Maharashtra, Goa, Gujarat, or Rajasthan	25.0	18.2	20.1
n	Number of unweighted persons 30 years and older in the sample[4]	56351	117169	173520

Notes:
1. Mean values are based on the weighted sample.
2. The reference category is kachcha Kachcha houses are made from mud, thatch or low-quality materials. Pucca houses are made from high-quality materials (such as bricks, tiles, cement, and concrete) throughout, including roof, walls, and floor. Semi-pucca houses are made from partly low-quality materials and partly high-quality materials.
3. Scheduled castes (SC) and scheduled tribes (ST) are those castes and tribes identified by the Government of India as socially and economically backward and in need of protection from social injustice and exploitation.
4. Actual sample size varies slightly for individual variables depending on the number of missing values.

Table 2: Unadjusted and adjusted effects of type of cooking fuel and other selected variables on the risk of tuberculosis among persons age 30 years and older, India 1992–93

Variable	Unadjusted		Adjusted	
	Odds Ratio	95% Confidence Interval	Odds Ratio	95% Confidence Interval
Cooking fuel type				
Biomass fuels	3.81	2.95, 4.93	2.75	2.07, 3.67
Cleaner fuels†	1.00	--	1.00	--
Separate kitchen				
Yes	0.59	0.52, 0.68	0.73	0.63, 0.83
No†	1.00	--	1.00	--
House type				
Kachcha†	1.00	--	1.00	--
Pucca or semi-pucca	0.58	0.51, 0.66	0.89	0.77, 1.02
Crowding				
<3 persons per room†	1.00	--	1.00	--
≥3 persons per room	1.20	1.06, 1.37	0.98	0.86, 1.12
Age				
30 – 39†	1.00	--	1.00	--
40 – 49	1.49	1.25, 1.78	1.45	1.21, 1.74
50 – 59	1.73	1.46, 2.07	1.67	1.39, 1.99
60 – 69	2.56	2.14, 3.06	2.22	1.85, 2.67
70 +	2.48	2.02, 3.05	2.08	1.67, 2.58
Gender				
Male†	1.00	--	1.00	--
Female	0.60	0.54, 0.68	0.55	0.48, 0.62
Residence				
Urban	0.52	0.43, 0.63	1.09	0.88, 1.34
Rural†	1.00	--	1.00	--
Education				
Illiterate†	1.00	--	1.00	--
Below high school	0.74	0.64, 0.86	0.83	0.71, 0.98
High school & above	0.30	0.23, 0.39	0.49	0.37, 0.65
Religion				
Hindu	0.77	0.61, 0.97	0.76	0.60, 0.97
Muslim†	1.00	--	1.00	--
Other	0.57	0.40, 0.82	0.66	0.46, 0.95
Caste				
SC/ST	1.37	1.19, 1.59	1.11	0.95, 1.31
Other†	1.00	--	1.00	--
Geographic region				
North and northeast	1.49	1.15, 1.93	1.40	1.07, 1.81
Central and eastern	1.29	1.07, 1.56	1.15	0.94, 1.40
West	1.01	0.80, 1.27	1.06	0.84, 1.33
South†	1.00	--	1.00	--
No. of unweighted cases	173393		168917	

† Reference category

Note: For definition of variables see text and Table 1. Both unadjusted and adjusted odds ratios are estimated by logistic regression. Confidence intervals take design effects due to clustering into account. Unadjusted odds ratios are based on separate logistic regressions for each predictor variable. Adjusted odds ratios are based on a single logistic regression consisting of all the predictor variables in the table. For any given predictor variable in the adjusted column, the set of control variables consists of all the other predictor variables. Models are based on the weighted sample.

Table 3: Effects of type of cooking fuel and other selected variables on the risk of tuberculosis among persons age 30 years and older by gender, India 1992–93

Variable	Male		Female	
	Odds Ratio	95% Confidence Interval	Odds Ratio	95% Confidence Interval
Cooking fuel type				
Biomass fuels	2.59	1.84, 3.64	3.06	2.00, 4.67
Cleaner fuels†	1.00	--	1.00	--
Separate kitchen				
Yes	0.71	0.61, 0.84	0.75	0.60, 0.94
No†	1.00	--	1.00	--
House type				
Kachcha†	1.00	--	1.00	--
Pucca or semi-pucca	0.86	0.73, 1.01	0.94	0.74, 1.18
Crowding				
<3 persons per room†	1.00	--	1.00	--
≥3 persons per room	0.97	0.83, 1.14	0.99	0.79, 1.24
Age				
30 – 39†	1.00	--	1.00	--
40 – 49	1.68	1.34, 2.10	1.19	0.89, 1.60
50 – 59	2.17	1.73, 2.73	1.10	0.83, 1.46
60 – 69	2.68	2.14, 3.37	1.68	1.26, 2.25
70 +	2.72	2.09, 3.52	1.29	0.88, 1.89
Residence				
Urban	1.09	0.85, 1.39	1.09	0.82, 1.47
Rural†	1.00	--	1.00	--
Education				
Illiterate†	1.00	--	1.00	--
Below high school	0.88	0.73, 1.06	0.67	0.47, 0.95
High school & above	0.49	0.35, 0.67	0.65	0.33, 1.27
Religion				
Hindu	0.82	0.62, 1.09	0.68	0.50, 0.93
Muslim†	1.00	--	1.00	--
Other	0.58	0.38, 0.89	0.79	0.47, 1.33
Caste				
SC/ST	1.13	0.94, 1.36	1.08	0.84, 1.40
Other†	1.00	--	1.00	--
Geographic region				
North and northeast	1.35	1.01, 1.81	1.45	0.99, 2.13
Central and eastern	1.02	0.81, 1.28	1.39	1.05, 1.83
West	1.10	0.86, 1.41	0.93	0.66, 1.32
South†	1.00	--	1.00	--
No. of unweighted cases	87749		81168	

† Reference category

Note: For definition of variables see text and Table 1. Odds ratios are estimated by logistic regression. Confidence intervals take design effects due to clustering into account. For any given predictor variable, the set of control variables consists of all the other predictor variables in the table. Models are based on the weighted sample.

Table 4: Effects of type of cooking fuel and other selected variables on the risk of tuberculosis among persons age 30 years and older by residence, India 1992–93

Variable	Urban		Rural	
	Odds Ratio	95% Confidence Interval	Odds Ratio	95% Confidence Interval
Cooking fuel type				
Biomass fuels	2.47	1.70, 3.58	2.76	1.79, 4.26
Cleaner fuels†	1.00	--	1.00	--
Separate kitchen				
Yes	0.69	0.48, 1.00	0.74	0.64, 0.85
No†	1.00	--	1.00	--
House type				
Kachcha†	1.00	--	1.00	--
Pucca or semi-pucca	0.89	0.63, 1.25	0.88	0.76, 1.03
Crowding				
<3 persons per room†	1.00	--	1.00	--
≥3 persons per room	1.14	0.80, 1.61	0.94	0.81, 1.09
Age				
30 – 39†	1.00	--	1.00	--
40 – 49	1.90	1.28, 2.83	1.36	1.11, 1.67
50 – 59	1.44	0.90, 2.29	1.71	1.41, 2.08
60 – 69	2.21	1.41, 3.44	2.23	1.82, 2.72
70 +	2.41	1.37, 4.22	2.03	1.60, 2.56
Gender				
Male†	1.00	--	1.00	--
Female	0.50	0.38, 0.65	0.56	0.49, 0.65
Education				
Illiterate†	1.00	--	1.00	--
Below high school	0.59	0.41, 0.84	0.90	0.75, 1.08
High school & above	0.35	0.21, 0.58	0.55	0.39, 0.77
Religion				
Hindu	0.83	0.54, 1.27	0.76	0.57, 1.01
Muslim†	1.00	--	1.00	--
Other	0.65	0.31, 1.35	0.67	0.44, 1.02
Caste				
SC/ST	1.03	0.67, 1.59	1.13	0.95, 1.34
Other†	1.00	--	1.00	--
Geographic region				
North and northeast	1.56	0.96, 2.54	1.33	1.00, 1.78
Central and eastern	1.48	0.98, 2.25	1.08	0.86, 1.34
West	0.98	0.58, 1.66	1.06	0.83, 1.37
South†	1.00	--	1.00	--
No. of unweighted cases	55568		113349	

† Reference category

Note: For definition of variables see text and Table 1. Odds ratios are estimated by logistic regression. Confidence intervals take design effects due to clustering into account. For any given predictor variable, the set of control variables consists of all the other predictor variables in the table. Models are based on the weighted sample.

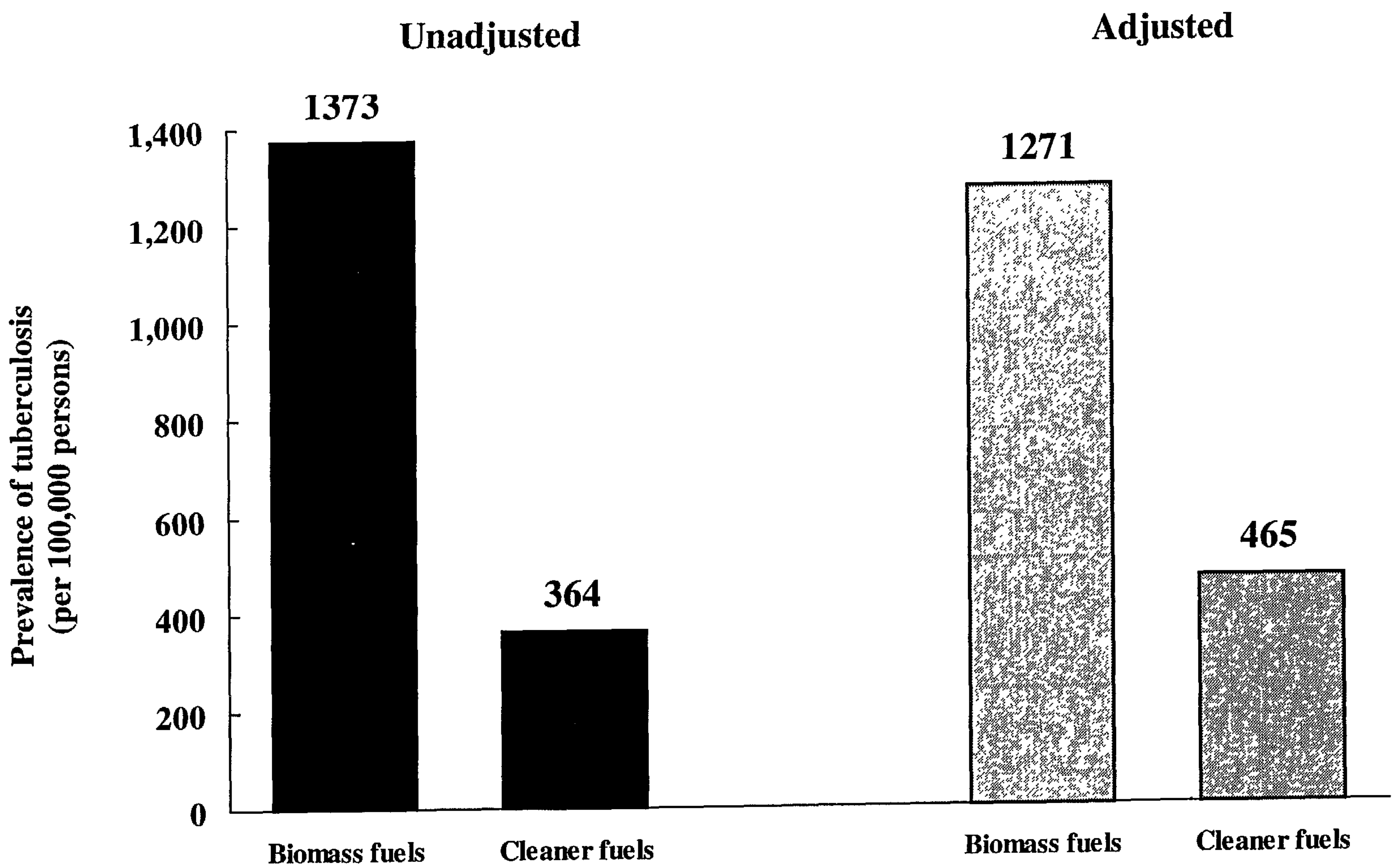

Figure 1: Unadjusted and adjusted prevalence of tuberculosis by type of cooking fuel: persons age 30 years or older, India 1992-93

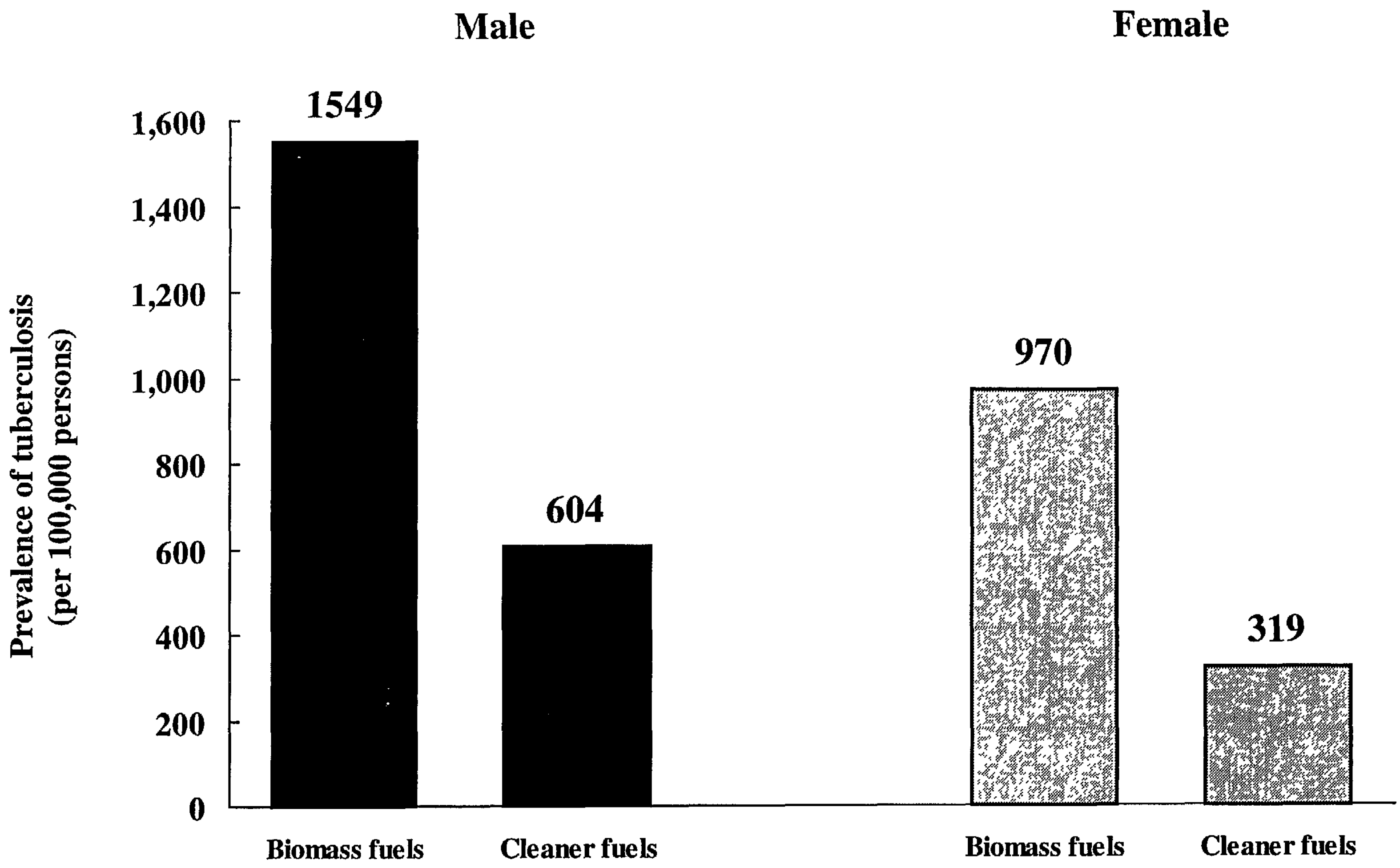

Figure 2: Adjusted prevalence of tuberculosis by type of cooking fuel and gender: persons age 30 years or older, India 1992-93

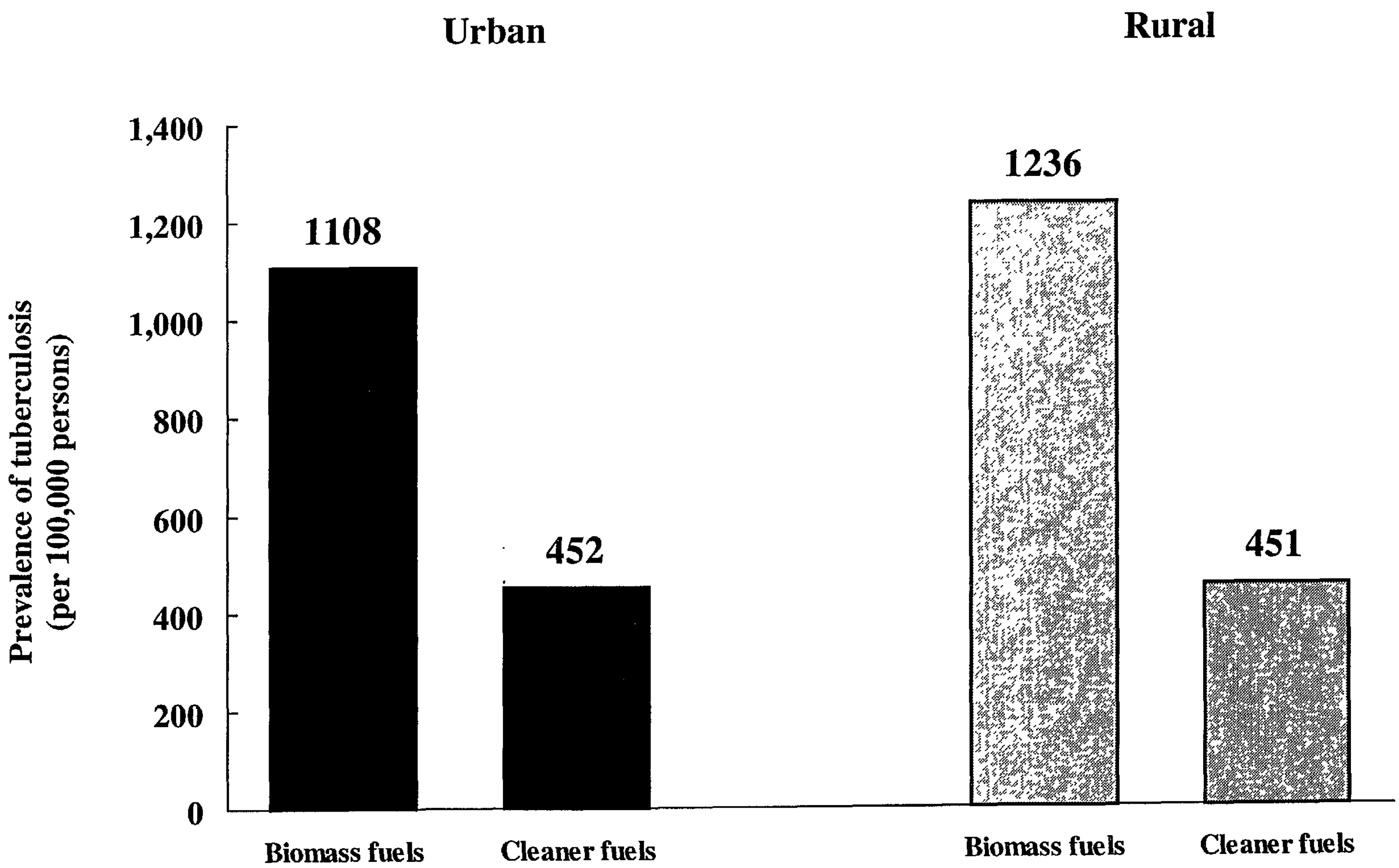

Figure 3: Adjusted prevalence of tuberculosis by type of cooking fuel and residence: persons age 30 years or older, India 1992-93