Health Risk Analysis of Heating Fuel Choice: Case Study in Kentucky

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Abstract:

Combustion-generated pollutants, principally those from solid-fuel including biomass and coal when cooking and heating, bring out a significant public health hazard in both developed and developing countries. Most of the existing studies addressing this issue focus on developing countries, and on exposure when cooking rather than heating. By using the Kentucky Homeplace Program data, this research explores the health risk associated with heating fuel choice. Logit model was applied to get the estimation. The results indicate that using polluting heating fuel increases the odds of suffering from respiratory disease, although this positive effect is not significantly strong. The study also shows the strong evidence that people having asthma or allergy condition are less likely to choose polluting heating, and using coal as heating fuel has significantly positive effect on the prevalence of respiratory disease. Some demographic, socioeconomic and lifestyle characteristics do have significant effects on the prevalence of the respiratory disease, asthma and allergy.

Keywords: *Combustion-generated pollutants, indoor air pollution, heating fuel choice, health risk*

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I. Introduction

Indoor air pollution (IAP) is a public health problem in both developed and developing countries (Ezzati M, Rodgers AD, et al, WHO, 2003). Of 20 leading health risk factors in very low and low income developing countries, IAP ranks, respectively, as the forth and eighth most important mortality risk factors (WHO, 2002; Ezzati et al, 2002). According to the American Medical Association (AMA), one-third of the national health bill is spent on causes directly attributable to indoor air pollution. In recent years, comparative risk studies performed by EPA and its science advisory board (SAB) have consistently ranked indoor air pollution among the top five environmental risks to public health.

Among the four components of indoor pollution (combustion products, chemicals, radon, and biologic agents), combustion-generated pollutants, principally those from solid-fuel including biomass (wood, charcoal, dung, and crop residues) and coal when cooking and heating, bring out a significant public health hazard predominantly affecting poor rural and urban communities, especially in developing countries. According to epidemiologic research results, biomass and coal smoke contain a large number of pollutants and known health hazards: particulate matter (PM), carbon monoxide (CO), nitrogen dioxide, sulfur oxides (mainly from coal), formaldehyde, and polycyclic organic matter, including carcinogens such as benzopyrene and benzene (Majid Ezzati et al. 2002). According to WHO's 2007 National Burden of Disease Estimates Report, exposure to indoor air pollution from solid fuels has been linked to some different diseases, including acute and chronic respiratory diseases, tuberculosis, asthma, cardiovascular disease, and perinatal health outcomes. In addition, the report from Sustainable Energy Development Office of government of west Australia states that some heaters that directly burn fuel (wood or kerosene) may also affect air quality inside the home.

Although some lower-income developing countries are typical research locations, the health concern of solid fuels combustion still exists in developed countries. Among the "dirtiest" types of heating and cooking systems are wood and coal stoves or fireplaces located in the living areas. Wood and coal are currently used in many areas of the world for both heating and cooking, and, up to the mid-20th century, were the main fuels used in what are now considered developed countries (Ezzati M, Rodgers AD, Lopez AD, et al, 2003). Many people now in the age range at risk for acute and chronic respiratory diseases and lung cancer experienced traditional heating and cooking sources when they were younger, especially those who grew up in rural areas. In addition, while some dirty fuels are no longer dominant in developed countries, there has been some increase in the past decade in the use of wood for heating and cooking, at least as a supplementary system (J.I. Zerbe, USDA Forest Products Laboratory, 2004). So it is imperative to clarify whether such exposures had any influence on health among people who experienced or are experiencing them.

However, most of studies that have been and are currently being performed on the health effects of indoor air pollution from solid fuel combustion focusing on developing countries based on the facts that biomass accounts for more than 50% of domestic energy use in many developing countries and for as much as 95% in some lower-income ones (Ezzati M, Kammen DM b.2002). Moreover, most research focuses on the health risk associated with the fuel smoke when cooking rather than heating. Finally, according to U.S. EPA, health hazards may be associated with indoor air pollution from combustion appliances while there is so little research address this issue before.

Using the Kentucky home-place health survey data, this paper will explore the health risk associated with heating fuel choice. The results should be initiatory and useful for both consumers to choose the right heating and policy makers to formulate corresponding energy policy. The specific objectives of the study were to:

- Quantify the exposure-response relationship for polluting heating and some specific disease (respiratory disease, asthma and allergy)

- Determine the extent to which some specific disease (respiratory disease, asthma and allergy) is related to socio-economic conditions of the clients in which they live.

The following section reviews the literature about the health effect of exposure to indoor air pollution from solid fuel combustion and the heating fuel consumption in U.S. The data source and statistic description are explained then, following by the empirical models adopted. Results are interpreted and conclusion and implications of this analysis are discussed.

II .Literature Review

i. Review of Empirical Studies

In the last decade, a number of quantitative epidemiological studies have been carried out to address the health effects of indoor air pollution from solid fuel combustion. By reviewed the epidemiological evidence of the health effects of indoor smoke from solid fuels, Bruce et al. (2000) concluded that, despite some methodological limitations, the epidemiological studies together with experimental evidence and pathogenesis provide compelling evidence of causality for acute respiratory infections and chronic obstructive pulmonary disease, particularly in conjunction with findings for environmental tobacco smoke and ambient air pollution. A number of epidemiological studies from developing countries, especially from China, provide the evidence to support the relationship between coal smoke (not biomass) and lung cancer, particularly in women (Smith K.R. et al. 1993, Du YX et al., 1996, Wang TJ et al., 1996, Liu BQ et al., 1998).

In recent years, some new evidence emerged suggesting that indoor air pollution (IAP) in developing countries may also increase the risk of other important child and adult health problems. It includes conditions such as asthma and middle ear infection for children, tuberculosis, nasopharyngeal and laryngeal cancer, and cataract in adults (Bruce N., Perez-Padilla R., 2000). It may also cause low birthweight, and perinatal mortality (still births and deaths in the first week of life) (Rehfuess and Rouse, 2005).

Broadly, most of the empirical studies focused on developing countries. Smith, K.R., (2000) evaluates the existing epidemiological studies and applies the resulting risks to the more than three-quarters of all Indian households dependent on solid fuels. According to Smith, sufficient evidence is available to estimate most confidently the risks for acute respiratory infections (ARI), chronic obstructive pulmonary disease (COPD), and lung cancer. Estimates for tuberculosis (TB), asthma, and blindness are of intermediate confidence. Estimates for heart disease have the lowest confidence. A consistent body of evidence, particularly from China, has shown that women exposed to smoke from coal fires in their homes have an elevated risk of lung cancer (Kleinerman R. et al., 2002, Zhou B. et al., 2000, Luo R. et al., 1996). Several studies in China have found cooking stove smoke to be a strong risk factor for lung cancer among nonsmoking women (Ko Y et al., 1997, Zhong L1999). There is also some evidence that stove improvements can substantially reduce indoor air pollution and the risk of lung cancer (Lan Q, 2002).

There are few empirical studies that address above issues in developed countries. In a population-based case-control study of lung cancer among white women in Los Angeles County, California, Wu et al. (1985), reported elevated risks for lung cancer in relation to reporting heating or cooking with coal burned on a stove or fireplace during childhood and the teenage years. In a case-control study of lung cancer carried out in Montreal in 1996–2001, Agnihotram V et al. (2007) collected information on subjects' lifetime exposure to coal and wood combustion when heating and cooking by means of a personal interview. Based on the odds ratios computed by a few indices of exposure to traditional heating and cooking sources, and a number of covariates including smoking, the results shows that there was no indication of excess risks among men, while there was higher risk (the odds ratio was 2.5) to have lung cancer for those women exposed to both traditional heating and cooking sources. Another case-control study in Eastern and Central Europe and the United Kingdom (Lissowska et al., 2005) show that the odds ratio of lung cancer associated with solid fuel use was 1.22 (95% confidence interval (CI): 1.04, 1.44) for cooking or heating, 1.37 (95% CI: 0.90, 2.09) for solid fuel only for cooking, and 1.24 (95% CI: 1.05, 1.47) for solid fuels used for both cooking and heating. The data suggest a modest increased risk of lung cancer related to solid-fuel use for cooking rather than heating.

Based on the reviews by Smith et al (2000) and Bruce et al (2000), the main emphasis is given to acute (lower) respiratory infections (ALRI), COPD, and lung cancer (due to coal) for which the evidence is the most robust. The high incidence and mortality of childhood ALRI means that this condition makes up by far the greatest proportion of the burden of disease attributable to indoor air pollution.

ii. Review of heating choices in the U.S.

From the Residential Energy Consumption Survey (RECS) data (2005), approximately 10.56 quadrillion Btus of energy were consumed for space heating in 2005 in the United States. The major energy sources for residential space heating, in descending order of percentage of end-use energy consumption housing units, are natural gas (52.4%), electricity (30.3%), fuel oil (6.9%), propane/liquefied petroleum gas (LPG) (5.4%), wood (2.6%), kerosene (0.6%) and other fuel (0.5%). Although most households in the U.S. use clean fuel (natural gas, electricity) as their main heating fuel, there are still issues to be noted.

First, among the "dirtiest" heating fuel, wood is still an important heating fuel in U.S, and coal is making a comeback as a heating fuel. About 2.9 million household (2.6% of the total housing units of the U.S.) use wood as the main heating fuel, and about 8.9 million household (8% of the total housing units of U.S.) use it as their secondary heating fuel. Residential wood combustion (RWC) is often perceived as environmentally dirty due to elevated emissions of fine particles from older wood burning devices (Robert C, James et al., 1998). Although the EPA has promulgated New Source Performance Standards (NSPS) for wood heaters which establish threshold particulate emission rates for wood heaters to be certified, only about 11% of the wood stoves currently in use are EPA certified, only 4% of the fireplace inserts are EPA certified, and only one state now requires new fireplaces to be certified (James E. Houck and Paul E. Tiegs. el, 1998). It means that the majority of wood is currently burned in older technology appliances and that the emission problem still exists and need to be identified. Burning coal at home had been declining for decades. Coal consumption for residential use hit a low of 258,000 tons in 2006. Then as the cost of heating oil and natural gas became increasingly prone to spikes, the relatively cheap coal started to rise as a residential heating fuel. According to the Energy Information Administration, residential coal consumption jumped 9 percent in 2007 and 10 percent more in the first eight months of 2008.

Second, indoor air pollution is potentially associated with combustion appliances such as space heaters, ranges, ovens, stoves, furnaces, fireplaces, and water heaters. Typical fuels for these combustion appliances include gas, both natural and liquefied petroleum (LP), kerosene, oil, coal, and wood. From RECS data (2005), about 7.9 million households (7.1% of the total households units in the U.S.) use combustion appliances as their main heating fuel. About 12.1 million households (10.9% of the total households units in the U.S.) use combustion appliances as their secondary heating fuel. Most combustion heating appliances are vented to the outside of buildings to facilitate removal of the products of combustion, which include carbon monoxide, carbon dioxide, nitrogen dioxide, and water vapor. However, some combustion heating devices may be unvented (e.g., kerosene- and propane-fueled space heaters, some gas-fueled log sets, and cooking devices used improperly for heating), and the use of such unvented devices in closed settings may be associated with health risks because of exposure to polluting emissions.

Finally, “fuel poverty” still exits in the U.S. The term of “fuel poverty” was first established by Dr. Brenda Boardman in her book with the phrase as its title, first published in 1988 and mainly used in the UK, Ireland and New Zealand. In the UK, “fuel poverty” is said to occur when in order to heat its home to an adequate standard of warmth a household needs to spend more than 10% of its income on total fuel use. A fuel poor household is one which cannot afford to keep adequately warm at reasonable cost. From RECS data (2005), of the 2.9 million household units using wood as their main heating fuel, 2.3 millions household (about 79%) live in the rural area. About 57% (0.4 million out of 0.9 million) of the household using kerosene as the main heating fuel was located in rural areas. The U.S. Department of Energy reports that heating fuels may be limited to propane and wood for people in rural areas (EERE 2008).

Despite the evidences suggesting potential links between heating options and individuals' health risk in developed countries, few studies have examined their correlation. In this study, we investigate the health risk associated with polluting heating option in Kentucky, particularly in the rural areas.

III. Data

The Kentucky Homeplace health survey data was used for the econometric analysis. The surveys are the initial interview with the client who wants to enroll in the Kentucky Homeplace Program. Kentucky Homeplace Program was established in 1994 by the state Assembly. The program was to hire people from the affected communities and train them to be family health care advisors (FHCAs). These FHCAs would then provide a variety of health and social services to people living in their communities to improve the commonwealth of the residents. The survey information was used to help the client (survey respondent) access the social and health system as well as for research purpose.

The survey data are cross-sectional data of 2005 and 2006. The information includes client's socio-demographic, medical, environmental, occupational, and lifestyle characteristics. The key information for this research is the response to the question: "What type of heat do you have (check all that apply)?" One client may choose more than one type of heating fuel from electric, gas, coal, wood, fuel oil, kerosene, and other and give any comments.

The total observation of the database is 35780. Excluded observation with the missing value of heating choice (24936) , observation with no heating choice (953), observation choose "other" heating type but not showing the valid information about the heating type he use in the "explain"(42), the cleaned study sample size is 9849 individuals**.** Statistics of variables used in the analysis are reported in Table 1.

The characteristics of the sample are described as follows. Except "white, eduy, income, exercise, smoker, ca, chro" (there are small missing value exists in these variables), every variables in the model has 9849 observation. The average age of respondents is 53 years old, which is higher than reported median age of 36 for Kentucky residents (Kentucky Demographics 2005). 37% of the respondents are male and 95% of the sample are white (not Hispanic or Latino). The average length of education is 11 years. Among 9687 respondents, the average annual income is about $12,711 which is much lower than the state average of $46,214 a year (Kentucky Demographics 2005). About 57% of the respondents are fully or partially covered by public health insurance. About 44% of the respondents participate in physical activities, and 52% have used tobacco products. About 24% of the respondents suffer from heart disease while about 1.1% of the respondents have cancer/malignant neoplasm. About 7.2%, 7%, and 6.6% of the sample suffers from respiratory disease, allergy, and asthma, respectively. There is 62.8% of the total sample suffering from some chronic disease.

In descending order, the percentage of heating fuel used by the sample housing units are electricity (66.8%), gas (29.9%), wood (7%), kerosene (3.8%),coal (3.4%), fuel oil (0.6 %), and other fuel (0.2%). Based on the heating fuel choice from the survey, two categories were created and used in this study:

1. Non-Polluting Heating (nph) --- including heating choices of "electric, gas, propane."

2. Polluting Heating (ph) --- including heating choices of "coal, wood, fuel oil, kerosene, others (with valid statement information in "explain").

When classified the "others" choice into the category, some rules were followed as following:

a. If the client chooses "other," but he/she explain it is "propane," he/she is classified into the category of "nph."

b. If the client chooses "other," but he/she explain "pellet stove" "fire place," we assume they will use some "wood "or "other" heating, then they are classified into "ph;"

c. If the clients choose "geothermal," they are classified into "nph."

Because the client can choose more than one heating fuel, there are some observations (519 obs., about 5.27% of the total sample) using both “ph” and “nph.” For this part of observation, most of them using some polluting heating such as wood, coal burned in the fireplace, furnace as the secondary heat such as space heater, which is the main pollution smoke source show in the literature research. So this part of observation was classified as “ph” user because we can not ignore these important study objectives.

Based on the literature review and the data information, the heating choice maybe associated with the following diseases: respiratory disease, asthma, allergy, and lung cancer. In our data set, just 1.1% of the respondents have Cancer/Neoplasms – Malignant. Moreover, the data does not provide the specific information on lung cancer. Therefore we focus on respiratory disease, asthma, and allergy. The sample distribution, cross frequency table, and Z test results for difference between two proportions were shown in tables 2 and 3.

From table2, 86.85% of the sample use non-polluting heating while 13.15% use polluting heating. As our expectation, the prevalence of respiratory disease is higher within clients using polluting heating than that of within the non-polluting heating user group (8.19% to 7.08%). However, Z test results show that the difference is not significant. We also find that, the prevalence of asthma and allergy within respondents using polluting heating is lower than that of non-polluting heating users. The Z test results show that we can reject the null hypothesis, and conclude that these differences are significant.

In table 3, we found the polluting heating using rate is lower within people having asthma and allergy condition than that of those without these conditions. Moreover, Z test results indicate that these differences are significant. While Z test shows that there is no significant difference between the polluting heating using rates within people suffering with respiratory disease and those who do not.

Based on the above results, the two-way estimation of the association between disease prevalence rate and the heating fuel choice should be included in the regression in the next part.

From table 4, the prevalence of respiratory disease is significantly higher within people using coal for heating than that of people not using it (12.12% to 7.06%). The prevalence rate of respiratory disease related to using wood and kerosene as heating fuel are higher than that associated with not using them (7.64% to 7.2%, 7.8% to 7.21%). However, Z test cannot reject the null hypothesis that there is no significant difference between the proportions. Prevalence rate of asthma and allergy within people using any of polluting heating are lower than that of people not using it. The above unexpected results need further identification in the model regression in the next part.

IV. Model

Logit Model was used to do the analysis. The basic model specification is as following:

Let Yi = Event that the client has some specific condition (respiratory, asthma, allergy)

$Yi \in \{0,1\}$, i= 1,2,…N .

X_{ik} = ith explanatory variable

where X is non-negative.

Some specific condition Y_i may be explained by the following variables.

$Yi=f(X_{i1}, \dots X_{ik})$ (1.1)

Therefore,

$$E(Yi) = f(X_{i1}, \dots, X_{ik}) \dots\dots (1.2)$$

Assuming a linear function,

$$E(Y_i) = f(X_{i1}, \dots, X_{ik}) = \sum b_k X_{ik} \dots\dots (1.3)$$

The structural form of equation (3) is as follows;

$Y_i^* = \sum b_k X_{ik} + u_i$……………………………...…………………(1.4)

Y_i^* = latent event of disease incident.

b_k = measures the effect of exogenous variable on the average value of Y

Therefore using the logit model, the event of a person suffering from some specific disease given all other explanatory is;

$P(Y_i=1|X_i) = \exp(\sum b_k X_{ik})/(1+\exp(\sum b_k X_{ik}))$……….……………………(1.5)

$Y_1, Y_2, \ldots\ldots\ldots, Y_N$ are statistically independent.

No exact or near linear dependencies exist among the X_{ik}.

Logit parameters are estimated by Maximum Likelihood Estimation (MLE) method. The objective of MLE is to explain the probability of observing a particular sample of N values of Y given all sets of values X_i.

That is,

$P(Y|X) = \prod_{i=1}^{N} P_i^{Y_i}(1-P_i)^{1-Y_i}$……………………………………………..(1.6)

In MLE we proceed to find b so as to maximize the logit likelihood.

Thus, our regression equation is expressed as follows:

$L(Y|X,b) = \prod_{i=1}^{N}[\exp(\sum b_k X_{ik})/(1+\exp(\sum b_k X_{ik}))]^{Y_i}[\exp(\sum b_k X_{ik})/(1+\exp(\sum b_k X_{ik}))]^{1-Y_i}$…(1.7)

Base on the model specification discussed above, 9 equations were estimated.

To explore the effect of heating fuel choice on some specific diseases, following equation were estimated:

$resp_i = f(ph_i, age_i, white_i, eduy_i, male_i, income_i, exercise_i, smoker_i)$ (1)

$asm_i = f(ph_i, age_i, white_i, eduy_i, male_i, income_i, exercise_i, smoker_i)$ (2)

$alg_i = f(ph_i, age_i, white_i, eduy_i, male_i, income_i, exercise_i, smoker_i)$ (3)

To explore the effect of health condition on heating fuel choice, following equation were estimated:

$ph_i = f(resp_i, age_i, white_i, eduy_i, male_i, income_i, exercise_i, smoker_i)$ (4)

$ph_i = f(asm_i, age_i, white_i, eduy_i, male_i, income_i, exercise_i, smoker_i)$ (5)

$ph_i = f(alg_i, age_i, white_i, eduy_i, male_i, income_i, exercise_i, smoker_i)$ (6)

To identify the health risk associated with specific heating fuel choice, following equation were estimated:

$resp_i = f(age_i, white_i, eduy_i, male_i, income_i, exercise_i, smoker_i, ele_i, gas_i, coal_i, wood_i, foil_i, kero_i,)$ (7)

$asm_i = f(age_i, white_i, eduy_i, male_i, income_i, exercise_i, smoker_i, ele_i, gas_i, coal_i, wood_i, foil_i, kero_i,)$ (8)

$alg_i = f(age_i, white_i, eduy_i, male_i, income_i, exercise_i, smoker_i, ele_i, gas_i, coal_i, wood_i, foil_i, kero_i,)$ (9)

V. Results

SAS PROC LOGISTIC was used to get the estimation results. 9539 observations were used in the regression. Tables 5, 7, and 9 report the estimation results of the Logit Models applied to equations 1-9. The estimated odds ratios (reported in tables 6, 8, and 10) give a better way to interpret the coefficient estimates. Some of the results are consistent with expectation while some striking differences are revealed.

The likelihood ratio (LLR) and P- value show in table 5 tells us that each model as a whole fits well. The coefficient of age is positive and significant at 1% level for the prevalence of respiratory disease, but it is not significant for prevalence of asthma and allergy. White people have about 0.66 and 0.80 higher odds of suffering from respiratory disease and allergy respectively. Compared to female, male has about 0.42 and 0.45 lower odds to suffer from asthma and allergy. Education year has significantly negative and positive effect on the prevalence of respiratory disease and allergy respectively. However, odds ratio doesn't show a strong difference. Both exercise and smoking have significantly positive and negative effect, respectively. People who participate in physical activities have lower odds (0.21 to 0.15) of suffering from respiratory disease and asthma than people who do not, which is consistent with our common knowledge. However, people who participate in physical activities have higher odds (0.35) to have allergy. This may be because allergy is more related to environmental and genetic factors. Smoking has a very strong effect on the prevalence of respiratory disease and asthma. Holding other factors constant, odds ratios of suffering from respiratory disease and asthma for smoking people, respectively, are 2.59 and 1.64 times of the ones for non-smoking people. Smoking people do have lower odds to have allergy condition, holding other factors constant. As our key interests, the odds ratio indicate that polluting heating user has 0.1 higher odds of suffering from respiratory disease than the non-polluting heating users. The coefficient is positive but not significant. This could be due to the following reasons: first, some of the observations use more than one heating fuel, and therefore we cannot make definite conclusions about the effect of certain fuel. Secondly, exposure to pollution smoke was ascertained indirectly by type of fuel used for heating. This inaccurate measure just is a proxy for actual personal exposure to the pollution. The measurement problem reduces the reliability of the estimation of the exposure-response relationship. Finally, there is a number of confounding factors such as exhaust gas from automobiles, outdoor air pollution, and industrial pollution that may expose people to tracheal infections, yet their effects have not been captured in this particular study.

The polluting heating user has lower odds to have asthma and allergy. This is out of our expectation, but consistent with the sample cross frequency results discussed.

From table 7, the likelihood ratio (LLR) and P- value indicate that the models 4-6 fit well as a whole. Whether the respondent is suffering from respiratory disease or not has no significant effect on their choice to use polluting heating. While whether suffering from asthma or allergy has a significant negative effect on people's polluting heating choice. From table 8, respondents with asthma have 0.29 lower odds to use polluting heating, and those with allergy have 0.30 lower odds to choose polluting heating. These results are very interesting and can help to explain the estimation results from model 2 and model 3. Unlike acute respiratory disease, asthma is one form of chronic lung disease, and allergy is the 5th leading chronic disease in the U.S (Asthma &Allergy Foundation of America, 2005). The results may be explained by the defensive behavior. People having either of these two chronic diseases think that using non-polluting heating may relieve the symptoms of the disease and then choose non-polluting heating to reduce health risk. Because most acute respiratory diseases – the other common branch of respiratory disease – are suddenly viral infections, there is no strong motivation for people to take some defensive behavior (like shifting to use non-polluting heating) after the infection passes. In terms of other variables, age and income are significantly negative at 1% percent with much small coefficients. White people have higher odds of using polluting heating. Education year is strongly significant negative, which indicate that holding other factors constant, people with higher education level are less likely to use polluting heating.

The likelihood ratio (LLR) and P- value reported in Table 9 show the goodness of the model fit cross model 7 to model 9. The effect of age and income for the prevalence of the three diseases are very little while the effect of race is more prominent. Holding other factors constant, white people are more likely to suffer from respiratory disease and allergy. Female are more likely suffering from asthma and allergy, which is consistent with the evidence from The Asthma and Allergy Foundation of America (AAFA). Same as in the model 1—model 3, education year has significantly negative and positive effect on the prevalence of respiratory disease and allergy respectively while odds ratio don't show very strong difference. The effects of smoking and exercise are totally same as in the model 1—model 3(the odds ratio are almost same). The people who participates physical activity have lower odds of suffering from both of respiratory disease and asthma, higher odds to have allergy condition. Smoking people has much higher odds (2.6, 1.64) to suffer from respiratory disease and asthma while lower odds (0.87) to have allergy condition, , holding other factors constant. As for the specific heating fuel type, except coal has significant (at

5% level) positive effect on the prevalence of respiratory disease, all other heating fuel has no significant effect on the occurrence of respiratory disease, asthma and allergy. People using coal as heating fuel has 0.51 higher odds to suffer from respiratory disease than the people do not using it. The 95% CI (confidence interval) of coal doesn't include zero, which rejects the null hypothesis that the coefficient equals zero and supports the conclusion that the variable coal has significant effect on the prevalence of respiratory disease.

VI. Conclusion and Discussion

Using the Kentucky Homeplace Program health survey data, the relationship between the heating fuel choice and the associated health risk were estimated by Logit regression. Consistent with previous literature evidence, using polluting heating fuel (including coal, wood, fuel oil, and kerosene) increases the odds of suffering from respiratory disease. However, this positive effect is not significantly strong. Using polluting heating does not have significant effect on the prevalence of asthma and allergy. However, we do find the strong evidence that the people having asthma are less likely to choose using polluting heating (at 5% significant level) and people having allergy has lower odds to choose polluting heating (at 1% significant level). These results may be explained by defensive behavior. Further causality tests between the prevalence of asthma, allergy, and heating fuel choice need to be conducted.

Moreover, this case study presents the evidence that using coal as heating has significantly (at 5% level) positive effect on the prevalence of respiratory disease. Holding other factors constant, people using coal as heating fuel has 0.51 higher odds to suffer from respiratory disease than the people do not using it.

Some demographic and personal characteristics do have significant effects on the prevalence of these three diseases. Female are more likely to suffer from asthma and allergy, which is consistent with the existing academic evidence. Respiratory disease and allergy are more prevalent among white Americans than other races. Personal lifestyle also affects the prevalence of these diseases. People who participate in physical activities have lower odds of suffering from both respiratory disease and asthma. Smoking people are more likely to suffer from respiratory disease and asthma, holding other factors constant.

Although this initiatory study does reveal some interesting results, it is limited by a lack of detailed data on the exposure on the pollution. In this study, indirect and inaccurate measures (heating fuel type) were used as proxies for personal exposure of the pollution smoke. This indirect approach to exposure estimation clusters many people into a single exposure category without adequately capturing the influence of exposure variables such as the type and the location of heater, type of stove, type of fuel on actual exposures and the time exposed to the pollution smoke. According to recent findings on large variations in emissions from individual stove types (Ezzati M., 2000, Ballard-Tremeer G., 1996) and in exposure profiles within individual households (Boleij J.S.M., 1989, Saksena S., 1992, Ezzati M., 2000), the aggregate analysis and grouping of individuals reduce the reliability of the estimation of the exposure-response relationship. Lack of quantitative exposure information has prevented drawing definitive conclusions and the development of accurate dose-response relationship. In addition, some of the confounding factors that may expose people to tracheal infections, such as outdoor air pollution and industrial pollution, have not been captured in this study.

The measurement of personal exposures to smoke particles at home is technically demanding, involving moderately expensive equipment, careful procedures, and quality control and well-trained staff. These methodological complexities are one reason why direct measurement of pollution exposure has rarely been carried out. However, to get the more accountable estimation, developing methods for exposure assessment should be an important priority for further research in this field.

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Table1. Descriptive statistics of variables used in the analysis

Variable	N	Mean	Median	Std Dev	Definition
Age	9849	52.799	53	15.049	continuous; age of the respondent
male	9849	0.372	0	0.483	dummy; = 1 if male
white	9845	0.954	1	0.209	dummy; = 1 if race is "White (not Hispanic or Latino)"
eduy	9839	10.702	12	2.438	continuous; years of education
income	9687	12711.44	11640	8081.47	continuous; respondent's household total yearly income
InsYn	9849	0.464	0	0.499	dummy; = 1 if has health insurance
exercise	9752	0.441	0	0.496	dummy; = 1 if participate in any physical activity
smoker	9797	0.524	1	0.499	dummy; = 1 if have ever used tobacco product
ele	9849	0.668	1	0.471	dummy; = 1 if use electric as heating type
gas	9849	0.299	0	0.458	dummy; = 1 if use gas as heating type
coal	9849	0.034	0	0.180	dummy; = 1 if use coal as heating type
wood	9849	0.070	0	0.256	dummy; = 1 if use wood as heating type
foil	9849	0.006	0	0.078	dummy; = 1 if use fuel oil as heating type
kero	9849	0.038	0	0.191	dummy; = 1 if use kerosene as heating type
oth	9849	0.002	0	0.048	dummy; = 1 if use "other" heating type
ph	9849	0.131	0	0.338	dummy; = 1 if use polluting heating fuel
asm	9849	0.066	0	0.249	dummy; = 1 if suffer from asthma
hrt	9849	0.243	0	0.429	dummy; = 1 if suffer from heart disease
ca	9842	0.011	0	0.105	dummy; = 1 if suffer from 'Cancer/Neoplasms - Malignant
alg	9849	0.070	0	0.255	dummy; = 1 if suffer from Allergy
resp	9849	0.072	0	0.259	dummy; = 1 if suffer from Respiratory disease
chro	9842	0.628	1	0.483	dummy; = 1 if suffer some chronic disease

Table2. Cross frequency and Z test results for disease prevalence rate in different heating user groups

Characteristic	Sample Distribution (%)	Res Prevalence(%)	Asm Prevalence(%)	Alg Prevalence (%)
Ph=1	13.15	8.19	4.94	4.86
Ph=0	86.85	7.08	6.89	7.34
Z test Statistic		-1.426	2.620***	3.252***
P-value		0.154	0.009	0.001

*, **, and *** represent significant at the 10%, 5%, and 1% significance levels respectively.

Table3. Cross frequency and Z test results for polluting heating using rate in different health condition user groups

Characteristic	Sample Distribution (%)	ph using rate
resp=1	7.23	14.89
resp=0	92.77	13.01
Z test Statistic		-1.426
P-value		0.154
asm=1	6.63	9.8
asm=0	93.37	13.39
Z test Statistic		2.620
P-value		0.009***
alg=1	7.02	9.12
alg=0	92.98	13.45
Z test Statistic		3.252
P-value		0.001***

*, **, and *** represent significant at the 10%, 5%, and 1% significance levels respectively.

Table4. Cross frequency and Z test results for disease prevalence rate in different heating fuel user groups

Heating choice (hc)	resp Prevalence(%)			asm Prevalence(%)			alg Prevalence(%)		
	(hc=0)	(hc=1)	Z test Statistic (P-value)	(hc=0)	(hc=1)	Z test Statistic (P-value)	(hc=0)	(hc=1)	Z test Statistic (P-value)
ele	7.68	7	1.225 (0.221)	6.49	6.7	-0.396 (0.692)	6.92	7.06	-0.269 (0.788)
gas	7.32	7.02	0.514 (0.608)	6.36	7.26	-1.646* (0.100)	6.64	7.91	-2.261** (0.024)
coal	7.06	12.12	-3.491*** (0.0005)	6.68	5.15	1.098 (0.272)	7.13	3.64	2.445** (0.014)
wood	7.2	7.64	-0.430 (0.667)	6.77	4.76	2.059** (0.039)	7.13	5.48	1.648* (0.099)
foil	7.23	6.56	0.203 (0.839)	6.65	3.28	1.055 (0.291)	7.04	3.28	1.146 (0.252)
kero	7.21	7.8	-0.430 (0.667)	6.7	4.84	1.416 (0.157)	7.13	4.03	2.297** (0.022)

*, **, and *** represent significant at the 10%, 5%, and 1% significance levels respectively.

Table 5.Coefficient estimates for prevalence of diseases

Variable	Equation1 (resp) coeff. (Std.Err.)	Pr > ChiSq	Equation2(asm) coeff. (Std.Err.)	Pr > ChiSq	Equation3(alg) coeff. (Std.Err.)	Pr > ChiSq
Intercept	-4.145*** (0.395)	<.0001	-3.470*** (0.3694)	<.0001	-3.860*** (0.369)	<.0001
Age	0.017*** (0.003)	<.0001	0.003 (0.003)	0.2811	0.000 (0.003)	0.951
white	0.5075** (0.2529)	0.0448	0.233 (0.2199)	0.289	0.588** (0.240)	0.0142
male	-0.064 (0.084)	0.4482	-0.552*** (0.094)	<.0001	-0.599*** (0.095)	<.0001
eduy	-0.039** (0.0173)	0.0227	0.027 (0.0181)	0.1429	0.066*** (0.018)	0.0002
income	0.00001* (0.000005)	0.0946	0.00001** (0.000005)	0.0151	0.00001*** (0.000004)	0.0075
exercise	-0.231*** (0.0823)	0.0051	-0.165* (0.0844)	0.0507	0.303*** (0.081)	0.0002
smoker	0.953*** (0.090)	<.0001	0.494*** (0.087)	<.0001	-0.141* (0.082)	0.0868
ph	0.093 (0.1139)	0.4155	-0.335** (0.1388)	0.0158	-0.372*** (0.138)	0.0071
N	9539		9539		9539	
LLR	185.9767		81.8657		116.9633	
P>ChiSq	<.0001		<.0001		<.0001	

*, **, and *** represent significant at the 10%, 5%, and 1% significance levels respectively.

Table 6.Odds ratio estimate of effects of polluting heating fuel choice, individual characteristics on the health risk

Variable	Equation1(resp)		Equation2(asm)		Equation3(alg)	
	OR	95% CI	OR	95% CI	OR	95% CI
Age	1.02	1.01, 1.02	1.00	1.00, 1.01	1.00	0.99, 1.01
white	1.66	1.01, 2.73	1.26	0.82, 1.94	1.80	1.13, 2.88
male	0.94	0.80, 1.11	0.58	0.48, 0.69	0.55	0.46, 0.66
eduy	0.96	0.93, 1.00	1.03	0.99, 1.06	1.07	1.03, 1.11
income	1.00	1.00, 1.00	1.00	1.00, 1.00	1.00	1.00, 1.00
exercise	0.79	0.68, 0.93	0.85	0.72, 1.00	1.35	1.16, 1.59
smoker	2.59	2.17, 3.10	1.64	1.38, 1.94	0.87	0.74, 1.02
ph	1.10	0.88, 1.37	0.72	0.55, 0.94	0.69	0.53, 0.90

Table 7.Coefficient estimates for polluting heating fuel choice

	Equation4(ph)		Equation5(ph)		Equation6(ph)	
Variable	coeff. (Std.Err.)	Pr > ChiSq	coeff. (Std.Err.)	Pr > ChiSq	coeff. (Std.Err.)	Pr > ChiSq
Intercept	-1.220*** (0.289)	<.0001	-1.209*** (0.289)	<.0001	-1.223*** (0.289)	<.0001
resp	0.082 (0.114)	0.4694				
asm			-0.343** (0.139)	0.0136		
alg					-0.361*** (0.138)	0.0091
Age	-0.007*** (0.002)	0.0007	-0.007*** (0.002)	0.0009	-0.007*** (0.002)	0.0009
white	0.944*** (0.210)	<.0001	0.948*** (0.210)	<.0001	0.956*** (0.210)	<.0001
male	0.101 (0.064)	0.1115	0.091 (0.064)	0.1538	0.090 (0.064)	0.1574
eduy	-0.115*** (0.013)	<.0001	-0.115*** (0.013)	<.0001	-0.114*** (0.013)	<.0001
income	-0.00002*** (0.00000)	<.0001	-0.00002*** (0.00000)	<.0001	-0.00002*** (0.00000)	<.0001
exercise	0.219*** (0.061)	0.0004	0.214*** (0.061)	0.0005	0.223*** (0.061)	0.0003
smoker	0.291*** (0.064)	<.0001	0.305*** (0.063)	<.0001	0.292*** (0.063)	<.0001
N	9539		9539		9539	
LLR	200.944		207.006		207.830	
P>ChiSq	<.0001		<.0001		<.0001	

*, **, and *** represent significant at the 10%, 5%, and 1% significance levels respectively.

Table 8.Odds ratio estimate of association between polluting heating choice and individual's health status and other characteristics

Variable	Equation4(ph)			Equation5(ph)			Equation6(ph)		
	OR	95% CI		OR	95% CI		OR	95% CI	
resp	1.09	0.87,	1.36						
asm				0.71	0.54	0.93			
alg							0.70	0.53,	0.91
Age	0.99	0.99,	1.00	0.99	0.99,	1.00	0.99	0.99,	1.00
white	2.57	1.70,	3.88	2.58	1.71,	3.89	2.60	1.72,	3.92
male	1.11	0.98,	1.25	1.10	0.97,	1.24	1.09	0.97,	1.24
eduy	0.89	0.87,	0.91	0.89	0.87,	0.91	0.89	0.87,	0.92
income	1.00	1.00,	1.00	1.00	1.00,	1.00	1.00	1.00,	1.00
exercise	1.24	1.10,	1.40	1.24	1.10,	1.40	1.25	1.11,	1.41
smoker	1.34	1.18,	1.52	1.36	1.20,	1.54	1.34	1.18,	1.52

Table 9.Coefficient estimates for prevalence of diseases given specific heating fuel choice

Variable	Equation7 (resp) coeff. (Std.Err.)	Pr > ChiSq	Equation8 (asm) coeff. (Std.Err.)	Pr > ChiSq	Equation9 (alg) coeff. (Std.Err.)	Pr > ChiSq
Intercept	-4.063*** (0.419)	<.0001	-3.607*** (0.396)	<.0001	-3.894*** (0.395)	<.0001
Age	0.018*** (0.003)	<.0001	0.003 (0.003)	0.3309	-0.001 (0.003)	0.7921
white	0.495* (0.253)	0.0506	0.245 (0.220)	0.2652	0.605** (0.240)	0.0117
male	-0.065 (0.084)	0.4419	-0.552*** (0.094)	<.0001	-0.599*** (0.095)	<.0001
eduy	-0.036** (0.017)	0.0409	0.026 (0.018)	0.1523	0.065*** (0.018)	0.0003
income	0.00001* (0.000)	0.0818	0.00001** (0.000)	0.0164	0.00001** (0.000)	0.0095
exercise	-0.235*** (0.082)	0.0044	-0.170** (0.085)	0.0448	0.298*** (0.081)	0.0002
smoker	0.954*** (0.091)	<.0001	0.493*** (0.087)	<.0001	-0.143* (0.082)	0.0812
ele	-0.130 (0.153)	0.3973	0.132 (0.158)	0.4042	0.027 (0.154)	0.8607
gas	-0.211 (0.154)	0.1709	0.167 (0.155)	0.2807	0.166 (0.151)	0.2712
coal	0.414** (0.208)	0.0468	-0.012 (0.276)	0.9669	-0.508 (0.317)	0.1088
wood	-0.159 (0.170)	0.3484	-0.301 (0.202)	0.1368	-0.145 (0.188)	0.4409
foil	-0.402 (0.541)	0.4578	-0.607 (0.734)	0.4085	-0.667 (0.733)	0.3631
kero	0.013 (0.219)	0.9522	-0.211 (0.262)	0.4207	-0.438 (0.282)	0.1207
N	9539		9539		9539	
LLR	194.791		84.181		123.045	
P>ChiSq	<.0001		<.0001		<.0001	

*, **, and *** represent significant at the 10%, 5%, and 1% significance levels respectively.

Table 10.Odds ratio estimate of association between specific heating fuel choice and health risk

Variable	Equation7(resp)			Equation8(asm)			Equation9(alg)		
	OR	95% CI		OR	95% CI		OR	95% CI	
Age	1.02	1.01,	1.02	1.00	1.00,	1.01	1.00	0.99,	1.01
white	1.64	1.00,	2.70	1.28	0.83,	1.97	1.83	1.14,	2.93
male	0.94	0.80,	1.11	0.58	0.48,	0.69	0.55	0.46,	0.66
eduy	0.97	0.93,	1.00	1.03	0.99,	1.06	1.07	1.03,	1.10
income	1.00	1.00,	1.00	1.00	1.00,	1.00	1.00	1.00,	1.00
exercise	0.79	0.67,	0.93	0.84	0.72,	1.00	1.35	1.15,	1.58
smoker	2.60	2.18,	3.10	1.64	1.38,	1.94	0.87	0.74,	1.02
ele	0.88	0.65,	1.19	1.14	0.84,	1.56	1.03	0.76,	1.39
gas	0.81	0.60,	1.10	1.18	0.87,	1.60	1.18	0.88,	1.59
coal	1.51	1.01,	2.28	0.99	0.58,	1.70	0.60	0.32,	1.12
wood	0.85	0.61,	1.19	0.74	0.50,	1.10	0.87	0.60,	1.25
foil	0.67	0.23,	1.93	0.55	0.13,	2.30	0.51	0.12,	2.16
kero	1.01	0.66,	1.56	0.81	0.49,	1.35	0.65	0.37,	1.12