Fuel for Life: Domestic Cooking Fuels and Women's Health in Rural China

PENG NIE[1,2*], ALFONSO SOUSA-POZA[1,3] AND JIANHONG XUE[4]

[1]*Institute for Health Care & Public Management, University of Hohenheim, Germany*
[2]*Food Security Center, University of Hohenheim, Germany*

[3]*IZA, Germany*

[4]*Department of Agricultural Economics, College of Economics and Management, Northwest A&F University, 3 Taicheng Road, Yangling, Shaanxi 712100, China*

*** Detailed contact information of authors**:

Peng Nie, Institute for Health Care & Public Management, University of Hohenheim, 70599 Stuttgart, Germany. Tel: +49(0)711 459 23423, Email: Peng_Nie@uni-hohenheim.de, Fax: +49(0)711 459 23953

Prof. Dr. Alfonso Sousa-Poza, Institute for Health Care & Public Management, University of Hohenheim, 70599 Stuttgart, Germany. Tel: +49(0)711 459 22584, Email: alfonso.sousa-poza@uni-hohenheim.de, Fax: +49-(0)711 459 23953

Prof. Dr. Jianhong Xue, Department of Agricultural Economics, College of Economics and Management, Northwest A&F University, 3 Taicheng Road, Yangling, Shaanxi 712100, China. Tel: +(86) 029-87081405 Email: xuej@nwsuaf.edu.cn

Abstract

Using longitudinal and biomarker data from the China Family Panel Studies (CFPS) and the China Health and Nutrition Survey (CHNS), this study examines the effects of fuel-based indoor air pollution on health among women aged ≥16 in rural China. With regards to three major domestic cooking fuels (including wood/straw, coal and liquefied natural gas (LNG)), we find that, compared to women in households that use dirty fuels like wood or straw, those in households using cleaner fuels like LNG for cooking have a significantly lower probability of suffering from chronic or acute diseases and are more likely to report better health. Even after controlling for unobserved individual heterogeneity, we also find some evidence that women in households using LNG are less likely to suffer from chronic or acute diseases. Relative to wood or straw, domestic coal use for cooking is associated with an increased risk of some cardiovascular diseases including high blood pressure. Longer time exposure to domestic cooking seems not increase the health burden of women.

JEL Classification Codes: I10, D10, J10; Q53

Keywords: domestic cooking fuels; health; women; rural China

* Correspondence author: Peng Nie, Institute for Health Care & Public Management, University of Hohenheim, 70599 Stuttgart, Germany. Email: Peng_Nie@uni-hohenheim.de.

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1. Introduction

Globally, 40% of the population relies on solid fuels, including coal and biomass (e.g. wood, charcoal, agricultural residues and dung), for domestic cooking, thereby breathing in a large amount of particulate matter (PM) and health-damaging pollutants which can be detrimental to health (United Nations Development Group, 2013). According to the 2010 Global Burden of Disease/Comparative Risk Assessment Project, exposure to indoor air pollution (IAP) from cooking with solid fuels resulted in 3.5 million premature death and various other health problems (e.g. lung cancer) in 2010 (Lim et al., 2012; Reid et al., 2012). Despite unprecedented economic development in China, most rural Chinese still use solid fuels for cooking, with 47.6% biomass and 13.5% coal in 2011 (Duan et al., 2014). More importantly, the use of solid fuels will more likely to continue even after 2030 (Zhang and Wu, 2012). IAP associated with solid fuels is estimated to be the largest single environmental risk contributor and ranks sixth among all risk factors examined for bad health in China (Zhang and Smith, 2007), resulting in over half a million premature deaths annually (World Health Organization and United Nations Development Programme, 2009).

Although a relatively large body of epidemiological and environmental literature examines the effects of IAP on health in China or rural China (Baumgartner et al., 2011; Finkelman et al., 1999; Jin et al., 2014; Kan et al., 2011; Liu et al., 2007a; Peabody et al., 2005; Smith et al., 2004; Zhang and Smith, 2007; Zhao et al., 2006), none assess this with nationally representative data and in a longitudinal setting.[1] So there is to date scant evidence on IAP and health in China as a whole, and the predominantly small-scale (mainly focusing on certain provinces or cities) cross-sectional analyses have limits in addressing confounders and the extent to which results can be generalized. Thus, the aim of this paper is to investigate the impacts of domestic cooking fuels on health outcomes of rural women aged ≥16 by using the China Family Panel Studies (CFPS) from 2010 to 2012 and the China Health and Nutrition

[1] As emphasized by Hao and Zhu (2004), a scientifically systematic evaluation of the effects of indoor air pollution on health has not been set up yet in China.

Survey (CHNS) from 1991 to 2009. We analyse different health impacts associated with three major household cooking fuels, namely, wood/straw, coal, and liquefied natural gas (LNG). We focus on women in rural China as they are predominantly responsible for cooking and thereby bear the brunt of the illness burdens associated with IAP (Zhang and Smith, 2007).

We contribute to the existing literature in three ways: First, we provide a comprehensive analysis of the health impacts related to domestic cooking fuels by using the most-recent nationally (the CFPS) and regionally representative (the CHNS) datasets. Second, we examine the impact of household cooking fuels on health within a panel setting, thereby facilitating us to capture some time-invariant individual heterogeneity. Third, using the 2009 CHNS biomarker data, we take a closer look at the association between IAP and some cardiovascular diseases, for which there is only limited evidence primarily due to the lack of reliable biomarker data (Fullerton et al., 2008).[2] This association can shed some new light on the mechanisms by which IAP from household cooking fuels may influence health outcomes.

In general, we find the evidence that, relative to wood/straw use, cleaner fuel use like liquefied natural gas for domestic cooking is associated with a decrease in the probability of chronic or acute disease whilst an increase in reported better health among women aged ≥16 in rural China. Longer time exposure to domestic cooking is not associated with an increase the health burden. Coal use for household cooking, compared to wood/straw, is associated with an increased risk in some cardiovascular diseases like high blood pressure.

The reminder of the paper proceeds as follows: Section 2 reviews the relevant research on this topic in China. Section 3 outlines the data and methodologies, and Section 4 reports empirical results. Section 5 concludes the paper.

2. Prior studies[3]

2.1 Fuel-based IAP and respiratory diseases

There is a growing literature in epidemiology and environmental sciences on investigating the association between fuel-based IAP and health in China and most of these studies present strong evidence that exposure to IAP is significantly related to the increased risk of bad health. With regard to the impact of fuel-based IAP on adult respiratory diseases, Liu et al. (2007b),

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2 As highlighted by Balakrishnan et al. (2014) and Zhang et al. (2013), biomarkers are regarded as one of more reliable measures of absorbed dose because of inter-individual differences associated with factors such as ventilation volume and breathing rate within a similar environmental concentration.

3 As in Fullerton et al. (2008), we also categorize the studies on the impact of fuel-based IAP on health in China into two groups: one is fuel-based IAP on respiratory diseases and another is on non-respiratory diseases.

based on a surveyed data in rural Yunyan of Guangdong province, show that for non-smoking women aged ≥40, using biomass fuel for cooking increases the probability of chronic obstructive pulmonary disease (COPD) when taking liquefied petroleum gas as the reference. Similarly, using a cross-sectional data in rural China (Shaanxi, Hubei and Zhejiang), Peabody et al. (2005) find that, compared with other types of fuels,[4] coal fuel is associated with an increased exhaled CO level, increased history of overall respiratory disease (including asthma, chronic bronchitis, emphysema, COPD and tuberculosis) and decreased forced vital capacity (FVC)[5] among adults aged ≥18. Xu et al. (2007), however, shows that there is no association between domestic cooking fuels and COPD in individuals aged ≥35 in Nanjing city. On the other hand, Pan et al. (2002) also suggest that IAP from fuel combustion for cooking and heating has adverse effects on asthma attack among respondents aged 15-65. By contrast, using a matched case-control approach in respondents aged ≥15 in Huaiyuan county of Anhui province, Kan et al. (2011) find that use of solid fuel for cooking is not associated with tuberculosis when cooking places have proper ventilation. One recent review by Lin et al. (2014) based on 15 international studies also indicates that the association between domestic use of solid fuels and tuberculosis is very low. Another recent review by Bentayeb et al. (2013) based on 33 international studies examines the detrimental respiratory impacts of IAP among elderly aged ≥65 and indicates that generally there is a significant association between IAP exposure and various short-term and long-term respiratory diseases, including wheezing, breathlessness, cough, phlegm, asthma, COPD.

Given that lung cancer is one of the serious health problems in China (see Chen et al., 2014; She et al., 2013), many studies have investigated the risk of lung cancer associated with fuel-based IAP. For example, one meta-analysis (Zhao et al., 2006) of 27 studies on air pollution and lung cancer risks in China provides evidence that odds ratios (OR) of the risk of lung cancer are 1.83 and 2.66 for women, and men and women in households using coal for heating and cooking, respectively. Likewise, another review (Smith et al., 2004) examines the health effect of IAP from coal use by using 9 single-province/city/municipality studies (seven in China[6], one in Japan and another in the U.S., including women or men and women separately) and finds that the OR of lung cancer risks among women is 1.17. Furthermore, there is an almost

[4] Cooking fuels include wood, crop fuel (crop residues and other biomass like dung), coal, charcoal and cleaner fuels (electricity, liquefied petroleum gas and biogas) (Peabody et al., 2005).

[5] FVC is the maximal volume of air exhaled with maximally forced effort from a maximal inspiration, i.e. vital capacity performed with a maximally forced expiratory effort (in liters at body temperature and ambient pressure saturated with water vapor) (see Miller et al., 2005).

[6] Cities/municipalities within those seven examined studies include Guangzhou, Harbin, Shenyang, Shanghai, Xuanwei, and Taiwan.

two-fold increase in risks (deaths from lung cancer) for women (OR=1.94) when restricting examined studies adjusted for smoking behaviour and a history of chronic respiratory disease. A more recent overview based on 23 studies (Kurmi et al., 2012), including 17 studies carried out in China, suggests that coal use is correlated with lung cancer compared with other types of biomass and the risk is more pronounced among Chinese females. Another interesting study by Kim et al. (2014), using a prospective cohort of women in urban Shanghai from 1996 to 2009, shows that cooking coal use with ever having poor kitchen ventilation (compared to never having poor kitchen ventilation) is significantly related to an increase in lung cancer risk, although not significant without controlling for ever poor ventilation. Cooking oil use, however, is not associated with a higher risk of lung cancer. Using a retrospective cohort of 37272 individuals in Xuanwei county of Yunnan province, Barone-Adesi et al. (2012) show that, compared with smokeless coal, use of smoky coal is related to an increased risk of lung cancer.

In addition, there are some studies provide strong evidence that coal use is associated with lung function impairment (Jie et al., 2014; Jin et al., 1995; Zhou et al., 2000). In contrast, it is interesting to note that, one recent study (Zhou et al., 2014), using a 9-year prospective cohort study among rural residents aged ≥40 in south China, shows that using clean fuels like biogas instead of biomass is correlated with better lung functions and a decrease in COPD risks.

2.2 Fuel-based IAP and non-respiratory diseases

A small body of literature in China examines the association between fuel-based IAP and cardiovascular diseases (CVD), especially high blood pressure. Baumgartner et al. (2011) find that exposure from indoor biomass combustion is associated with an increase in systolic blood pressure (SBP) and diastolic blood pressure (DBP) among women aged >50 in rural China. However, there is no association between the former and the latter in younger cohorts aged 25-50. This observation is confirmed by Baumgartner et al. (2014) that analyses data from 280 non-smoking women aged ⩾25 living in a rural region of northwestern Yunnan province, and shows that, relative to PM, exposure to pyrolytic biomass combustion has a much stronger association with blood pressure, inter alia, SBP.[7]

Some studies have investigated the association between domestic cooking fuels and certain poisonous endemics. For instance, Shraim et al. (2003) examine arsenic exposure associated with coal-burning in the population living in a small village at Guizhou province and find that

[7] Epidemiological studies in Taiwan provide some evidence that pollutant-based IAP might be an emerging risk factor for CVD, including blood pressure and heart rate increments (see Chuang et al., 2010; Chuang et al., 2013; Lin et al., 2009).

females are observed to have a higher dimethylarsinic acid levels but lower percentages of inorganic arsenic and monomethylarsonic acid than males. However, Finkelman et al. (1999) find that domestic coal combustion results in selenium poisoning and potential mercury poisoning.[8] This finding is also supported by Zheng et al. (2005); Li et al. (2006); Liu et al. (2007a). Li and Ma (2010) also confirm that an increase in CO poisoning occurrence is correlated with indoor coal burning, inadequate ventilations and inappropriate stove use.

In the context of our study, three aspects of the existing literature are worth mentioning: First, the empirical results for China generally suggest that fuel-based IAP has an adverse impact on both respiratory and non-respiratory health outcomes. Yet most existing studies in China cover only certain provinces or cities (see for instance Peabody et al., 2005) and no studies use nationally representative data. Second, nearly all studies use cross-sectional data; exceptions being Barone-Adesi et al. (2012) and Zhou et al. (2014) that use retrospective data to evaluate the impact of domestic cooking fuels on lung cancer and COPD, respectively. Third, only a limited number of studies have examined the association between fuel-based IAP and cardiovascular diseases (CVD) in China. Although IAP impacts on high blood pressure have been recently investigated (see Baumgartner et al., 2011; Baumgartner et al., 2014), relatively little is known about how IAP exposure from domestic cooking fuels is related to other types of CVD like inflammation.

The contribution of our study is to present nationally representative results using panel data in order to control for unobserved heterogeneity. Furthermore, it also takes a look at how domestic cooking fuels affect CVD, which might shed some light on the mechanisms through which IAP may operate on health outcomes.

3. Data and methods

In our analysis, we use data from the China Family Panel Studies (CFPS) and China Health and Nutrition Survey (CHNS). The CFPS, which is conducted by the Institute of Social Science Survey at Peking University, currently encompasses 2 waves collected in 2010 and 2012. It covers 25 provinces/municipalities/autonomous regions that represent 95% of the Chinese population, is a nationally representative sample and aims to capture socio-economic

[8] Excess fluorine is also associated with eating baked corn via burning high-fluorine coal briquettes (Finkelman et al., 1999).

development, as well as economic and non-economic well-being in Chinese households. [9] Our CFPS sample includes 11389 rural women aged ≥16 from 2010 to 2012.

The CHNS, which is comprised of 9 waves conducted in 1989, 1991, 1993, 1997, 2000, 2004, 2004, 2009 and 2011, covers 9 provinces (Liaoning, Heilongjiang,[10] Jiangsu, Shandong, Henan, Hubei, Hunan, Guangxi and Guizhou). The selected provinces differ in geographical and economic conditions and are regionally representative. The multistage random cluster design of this longitudinal dataset enables us to capture spatiotemporal dynamics in the social, economic and health situations of Chinese population. [11] Our final sample of the CHNS comprises 13624 rural women aged ≥16 from 1991 to 2009.

The data from the CFPS and the CHNS is used to examine the impact of domestic cooking fuels on health (including self-reported chronic or acute diseases and health status) of rural women. The advantage of the CFPS is that is it the first dataset that contains nationally representative information on health and cooking fuels. The CHNS is not nationally representative, but it has three other advantages which we exploit in this analysis: a long-running panel, information on time exposure to cooking, and, importantly, biomarker information which allows for a unique analysis of the association between cooking fuels and certain CVDs.

Health measures

In the CFPS, illness or having a disease is captured by the following question: *"Have you felt any physically discomfort during the preceding two weeks"*. This variable has a value equal to 1 if the respondent has felt discomfort, and 0 otherwise. In the CHNS, general health is captured by the following question: *"Have you suffered from a chronic or acute disease during the past 4 weeks?*" If the respondent has suffered from a chronic or acute disease, the dummy equals 1, and 0 otherwise.

Health status or self-reported health (SRH) is measured on a 5-point scale in the CFPS based on the following question: *"How would you rate your health status? 1=excellent, 2=very good, 3=good, 4=fair and 5=poor"*. We rescale the variable to range from 1=poor to 5=excellent. In the CHNS, SRH is captured by asking respondents the following question: "*Right now, how would you describe your health compared to that of other people in your age? 1=bad; 2=fair;*

[9] The CFPS excludes Hongkong, Macao, Taiwan, Xinjiang, Qinghai, Inner Mongolia, Ningxia and Hainan, and detailed information about sampling design is available from Xie et al. (2014).
[10] Note that Heilongjiang province was added as the ninth province in 1997.
[11] See Zhang et al. (2014) for more detailed information about the CHNS.

3=good; 4=excellent." Note that this information is only available for 1997 to 2006 in the CHNS. SRH covers not only mental and physical health but also subjective experience of acute and chronic diseases and overall feelings of well-being as well (Xie and Mo, 2014).

We also introduce dummies (1=yes, 0=no) for several major symptoms of diseases might be related to fuel-based IAP. The CFPS includes fever, pain, diarrhea, cough and palpitation, whereas the CHNS includes fever/sore throat/cough, diarrhea, asthma, eye/ear disease and heart disease/chest pain.

We use data from the CHNS on high blood pressure (HBP), systolic and diastolic blood pressure (SBP/DBP) and inflammation (C-reactive protein, CRP) as proxies for CVD. In the CHNS, blood pressure measurements are taken three times by a health professional using a mercury sphygmomanometer, with a time interval between successive pairs of measures of at least 1 minute. We calculate the average values of SBP and DBP based on the second and third measurements to overcome potential measurement biases. High blood pressure is a dummy variable equal to 1 if the respondent's SBP ≥140 mm Hg or DBP ≥90 mm Hg, or the respondent is taking anti-hypertension medications, 0 otherwise (Lei et al., 2012). Blood pressure information is available for the years between 1991 and 2009.[12] Inflammation is a dummy variable equal to 1 if the high sensitivity C-reactive protein exceeds 2 mg/dl, 0 otherwise (Yan et al., 2012). Note that the level of high sensitivity C-reactive protein is only available in the year of 2009 in the CHNS.

Household cooking fuels (HCF)

As in Peabody et al. (2005), we use three major household cooking fuels, namely wood/straw, coal and liquefied natural gas in our analysis. These are the three most commonly used fuels for domestic cooking, accounting for 83.2% in the CFPS and 83.5% in the CHNS of total household fuel consumption. The variable of household cooking fuels is grouped into three categories: 0=wood/straw, 1=coal and 2=liquefied natural gas (LNG), taking wood/straw as the reference group. As noted by Peabody et al. (2005), fuel types might be better proxies for pollution exposure compared to stove type, although both are only indirect measures of exposure to IAP. The fuel-based approach is, however, regarded as the most accurate technique for assessing IAP in developing countries (Mestl and Edwards, 2011).

[12] A detailed overview of blood pressure measurements in the CHNS is available in Lei et al. (2012).

Finally, we categorize the independent variables into two subgroups: individual and family characteristics:

Individual characteristics

Individual controls include age, squared age, educational level, marital status, job status, and current smoking behaviour. Education is measured on a 6-point scale: 1=illiterate, 2=primary school, 3=middle school, 4=high school, 5=vocational school and 6=university or higher. We recode it as a dummy variable. Marital status is a dichotomous variable equal to 1 if the respondent is married and 0 if the respondent is living together with his/her partner, divorced or widowed. Job status is a dummy variable equal to 1 if the respondent is currently employed and 0 otherwise. Current smoking behaviour is a binary variable equal to 1 if the respondent has smoked for the past month, 0 otherwise. Also note that the definitions of individual variables are generally the same in both the CFPS and the CHNS. One exception is time spent cooking that is only available in the CHNS, and which is measured by the following question: *"During the previous week, how much time (in hours) did you spend per day, on average, for cooking food for the household?"*

Family characteristics

Family controls include household income and household size. Note that household income is adjusted to 2012 in the CFPS and to 2011 in the CHNS, making household income more comparable across both datasets.

Estimation approaches

To investigate the association between domestic cooking fuels and general disease (also specific symptoms of illnesses) in a cross-sectional setting, we adopt a probit regression model of the following form:

$$GD_i = \alpha_0 + \alpha_1 HCF + \alpha_2 I_i + \alpha_3 F + \alpha_4 Y + \alpha_5 P + \varepsilon_i \quad (1)$$

Where GD_i is a binary variable indicating general chronic or acute disease or a specific disease symptom of individual *i*, and *HCF* denotes dummies for household cooking fuels, including wood/straw, coal and liquefied natural gas, with wood/straw as the reference group. I_i is a vector of individual *i*'s characteristics, *F* is a vector of family characteristics. *Y* is a vector of year dummies (with 2010 as the reference year in the CFPS and 1991 as the reference year in the CHNS), and *P* is a vector of provincial dummy variables (Liaoning as the reference province in the CFPS and the CHNS). α_1 is the key coefficient of interest and ε_i is the error term. Considering the multistage sampling design in the CFPS and the CHNS, we also take into account clustering at the village/neighbourhood level in the CFPS and community level in the CHNS.

Regarding the effects of household cooking fuels on cardiovascular diseases (i.e., high blood pressure and inflammation in the CHNS), we use the similar specification to equation (1) but without year dummies. With regards to SRH (measured on a 4-point scale in the CHNS and a 5-point scale in the CFPS), we estimate the impact of household cooking fuels on SRH using an ordered probit model, whose specification is similar to equation (1).

In order to take potential biases associated with individual unobservables into account, we examine the association between domestic cooking fuels and general disease by estimating the following random-effects probit model:

$$GD_{it} = I(X_{it}'\beta + F_t + \alpha_i + \varepsilon_{it} \geq 0) \qquad (2)$$

where GD_{it} denotes general chronic or acute disease of individual i at time t. $I(\cdot)$ is an indicator function that equals 1 if its argument $\cdot$ is true and 0 otherwise. X_{it} is a vector of individual characteristics including age and time spent on cooking. F_t captures family characteristics including household income and household size. α_i is assumed to be a random variable. [13]

[13] There is a paucity of studies taking a look at the possible endogeneity issue of household cooking fuels. As emphasized by Dulfo et al. (2008), most of existing evidence is based on observational studies, thereby making the causal effects of IAP on health difficult. And one crucial issue of observational studies is that individuals who have taken measures to improve IAP might do so primarily because they may be better informed, wealthier and more concerned about their health outcomes (Dulfo et al., 2008). Actually, Pitt et al. (2006), using the 2000-2003 Nutrition Survey of Bangladesh and the 1999 Rural and Demographic Survey in India, investigate the causal effect of time spent cooking on the occurrence of respiratory symptoms using fixed-effect instrumental variable approach. And they suggest that proximity to stoves is associated with poor health of women and the young children that they supervise. In order to identify a causal relationship between household cooking fuels and women's health, we also perform a special regressor model (SRM) which might be very useful for estimation of binary choice models when one or more regressors are endogenous or mismeasured (see a detailed introduction of SRM in Lewbel et al. (2012)). Following Lewbel et al. (2012), we adopt age as the special regressor mainly because it is both continuous and exogenous. In our case, instrument candidates include 2011 adjusted prices of coal briquette and liquefied natural gas in the community level. Taking wood/straw and coal as the reference, we do observe that there is no association between LNG and chronic/acute diseases, though the coefficient is negative. It is also the case for self-reported health (rescaled as a dummy variable, 1=excellent and good, 0=fair and poor) but its coefficient is negative. Note that it is quite difficult to make a relative comparison to the previous results due primarily to rescaling household cooking fuels and self-assessed health as a binary variable. Additionally, to ensure the strength of the instruments, we confirm the exogeneity of instrumental sets by using Hansen's J statistics (for self-reported disease: Hasen's J statistics=0.34, p-value=0.56; for self-reported health: Hasen's J statistics=0.17, *p-value*=0.68) and weak instrument identification via Wald-F statistics (for self-reported disease: Wald-F statistics=59.4, *p-value*=0.00; for self-reported health: Wald-F statistics=43.5, *p-value*=0.00). These results indicate that our instruments are reasonable. The results are not reported here, but are available upon request. As emphasized by Lewbel et al. (2012), such an instrumental technique might be problematic primarily because the special regressor's conditional independence of error term could be violated due to the association of special regressors with some other endogenous variables. Furthermore, SRM imposes fewer assumptions on the distribution of error terms, thereby leading to larger standard errors and less precious estimation (see Lewbel et al., 2012).

Given that self-reported health is ordinal, we adopt a random-effects ordered probit estimation for self-reported health using a similar specification as equation (2) but introduce time spent cooking as a proxy of exposure to indoor air pollution associated with cooking fuels (see Peabody et al., 2005). The specific estimation model is as follows:

$$SRH_{it}^{*} = X_{it}\beta + \alpha_i + \varepsilon_{it} \tag{3}$$

$$SRH_{it} = \begin{cases} 1, & if\ SRH_{it}^{*} \leq c_1 \\ 2, & if\ c_1 < SRH_{it}^{*} \leq c_2 \\ \vdots & \\ K, & if\ c_{K-1} < SRH_{it}^{*} \end{cases} \tag{4}$$

where SRH_{it}^{*} (linked to the observed ordinal response categories SRH_{it}) is a latent variable of self-reported health for individual *i* at time *t*, X_{it} represents observed characteristics, and α_i is assumed as a random variable. *c* is a set of cut points c_1, c_2 …, c_{K-1}. K is the number of possible outcomes.[14]

To analyse the association between household cooking fuels and levels of SBP and DBP in the CHNS, we employ an ordinary least squares estimation (OLS) as follows:

$$CVD_i = \beta_0 + \beta_1 HCF + \beta_2 I_i + \beta_3 F + \beta_4 P + \varepsilon_i \tag{5}$$

where CVD_i is a continuous variable denoting the level of SBP/DBP of individual *i*, and *HCF* represents dummies for household cooking fuels. I_i is a vector of individual *i*'s characteristics, *F* is a vector of family characteristics. *P* is a vector of provincial dummy variables (Liaoning as the reference province). β_1 is the key coefficient of interest and ε_i is the error term. Considering the multistage sampling design in the CHNS, we also take into account clustering at the community level. A brief summary of health measures is available in Table 1.

Table 1 A brief summary of health measures

Health measures	Description	Definition	Data source	Years	Methodology
Self-reported acute/chronic disease	Have you felt any physically discomfort during the preceding two weeks?	A binary variable equal to 1 if the respondent has felt discomfort, and 0 otherwise.	the CFPS	2010-2012	Probit model Random-effect probit model
	Have you suffered from a chronic or	A dummy equals 1 if the	the CHNS	1991-2009	Probit model

[14] A specific application of the random effects ordered probit approach can be available in Alsakka and Gwilym (2010), which examines the sources of heterogeneity in sovereign credit ratings in emerging economies.

	acute disease during the past 4 weeks?	respondent has suffered from a chronic or acute disease, , and 0 otherwise			Random-effect probit model
Self-reported health (SRH)	How would you rate your health status? 1=excellent, 2=very good, 3=good, 4=fair and 5=poor	A 5-point scale ranging from 1=poor to 5=excellent	the CFPS	2010-2012	Ordered probit model Random effect ordered probit model
	Right now, how would you describe your health compared to that of other people in your age? 1=bad; 2=fair; 3=good; 4=excellent.	A 4-point scale ranging from 1=bad to 4=excellent	the CHNS	1997-2006	Ordered probit model Random effect ordered probit model
High blood pressure	Measurements are taken three times by a health professional using a mercury sphygmomanomete	A dummy equal to 1 if the respondent's SBP ≥140 mm Hg or DBP ≥90 mm Hg, or the respondent is taking anti-hypertension medications, 0 otherwise	the CHNS	2009	Probit model
Systolic blood pressure (SBP)	Measurements are taken three times by a health professional using a mercury sphygmomanometer	The average value of SBP based on the second and third measurements	the CHNS	2009	Ordinary Least Squared model
Diastolic blood pressure (DBP)	Measurements are taken three times by a health professional using a mercury sphygmomanometer	The average value of SBP based on the second and third measurements	the CHNS	2009	Ordinary Least Squared model

Inflammation	Using high C-reactive protein	a dummy equal to 1 if the high sensitivity C-reactive protein exceeds 2 mg/dl, 0 otherwise	the CHNS	2009	Probit model

4. Results

Descriptive statistics

Descriptive statistics are presented in Appendix Table A1 and A2 for the CFPS and CHNS, respectively. As can be seen in Table A1, the average age of rural women in the CFPS is around 46, which is quite similar (approximately 46.6) in the CHNS (see Table A2). Wood/straw is the predominant type of cooking fuel (CFPS: 64.5%; CHNS: 42.2%) compared to other two major fuels, in both used datasets (see Table A1 and A2 in the Appendix). The proportion of liquefied natural gas, as one of cleaner cooking fuel types, is higher in the CFPS (25.1%) than that in the CHNS (17.9%), which could result from different period coverage between the CFPS and the CHNS (the CFPS: 2010-2012; the CHNS: 1991-2009) and cleaner cooking fuels might be widely used in recent years. And the heterogeneity in those three major types of domestic cooking fuels might be attributable to the different coverage of geographical regions between the CFPS and the CHNS.

Cross-sectional evidence of HCF and health: the CFPS and the CHNS

Table 1 presents the pooled cross-section results for both the CFPS and the CHNS. As can be seen, compared with wood/straw, those women whose household relies on liquefied natural gas (LNG) are less likely to suffer from chronic or acute diseases (CFPS: Marginal effect (ME)=-5.4%; CHNS: ME=-2.2%) (see columns 1 and 3 in Table 2). Furthermore, women in households that use either coal or LNG are more likely to reported better health than those in households using wood/straw (self-reported excellent health status in our case). The point estimates for LNG are, however, larger than those of coal (CFPS: 3.6% for LNG versus 2.3% for coal; CHNS: 2.9% for LNG versus 1.6% for coal), suggesting that cleaner cooking fuels like LNG are indeed beneficial to health.

Table 2 Probit/ordered probit estimates for household cooking fuels on women's health in rural area: CFPS 2010-2012 & CHNS 1991-2009

Variables	CFPS		CHNS	
	(1)	(2)	(3)	(4)
	Chronic/Acute disease	SRH (excellent)	Chronic/Acute disease	SRH (excellent)
Coal	0.007	0.023**	-0.012	0.016**
	(0.020)	(0.010)	(0.009)	(0.007)
LNG	-0.054***	0.036***	-0.022*	0.029***
	(0.016)	(0.009)	(0.011)	(0.009)
N	13389	13389	13624	7900
Pseudo R^2	0.064	0.147	0.080	0.073

Note: The dependent variable is a dummy variable of whether the respondent has suffered from a chronic or acute disease (1=yes, 0=no) or self-reported health (SRH) measured on a 5-point-scale ranging from 1=poor to 5=excellent in the CFPS and a 4-point scale ranging from 1=poor to 4=excellent in the CHNS. Controls include dummies of household cooking fuel choices (0=wood/straw, 1=coal, 2=liquefied natural gas, wood/straw as the reference group), individual characteristics (including age, squared age, education level, marital status, job status, current smoking behavior, time spent on cooking), family characteristics (translog household income and household size), provincial dummies (Liaoning as the reference province both in the CFPS and the CHNS) and year dummies (2010 as the reference year in the CFPS and 1991 as the reference year in the CHNS). Marginal effects are reported (For SRH, marginal effects indicate the probability of excellent health). Village/neighbour or community-level clustered standard errors are in parentheses, * p < 0.1, ** p < 0.05, *** p < 0.01.

Panel evidence for HCF and health: the CFPS

Considering the possible existence of individual unobservables or omitted factors, we also estimate a random effects probit/fixed effects model based on the CFPS. As shown in Table 3, significant negative effects in households using LNG for cooking can still observed when using a random effects probit estimation (see columns 1). However, we can find positive and significant associations between coal/LNG use and health when using a random-effects ordered probit estimation, albeit the magnitudes differ (see columns 2).

Table 3 Random-effects probit/random-effects ordered probit estimates for household cooking fuels on women health in rural area: CFPS 2010-2012

Variables	Chronic/acute disease (1) Random effects probit	Self-reported health (2) Random effects ordered probit
Coal	-0.019	0.083**
	(0.061)	(0.037)
LNG	-0.154***	0.072***
	(0.043)	(0.026)
N	9772	10002

Note: The dependent variable is a dummy variable of whether the respondent has suffer from a chronic or acute sick (1=yes, 0=no) or self-reported health measured a 5-point-scale ranging from 1=poor to 5=excellent. Controls include domestic cooking fuels (0=wood/straw, 1=coal, 2=liquefied natural gas (LNG), wood/straw as the reference group), age, age squared, household income and household size. Standard errors are in parentheses, * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Panel evidence for HCF and health: the CHNS

We perform a similar panel analysis with the CHNS, but, in addition, control for a women's time spent on cooking (TSC). Cooking time is categorized into four groups: 1=TSC<1 hour/day, 2=1⩽TSC<2 hours/day, 3=2⩽TSC<3 hours/day, 4=TSC⩾3 hours/day, taking the group of TSC<1 hour/day as the reference group. The results are presented in Table 4. Three observations are worth emphasizing (see Table 4): Firstly, we find no significantly negative association between domestic LNG use and chronic/acute diseases when using random effects probit, though positively significant effects on self-reported health using random effects ordered probit estimation (see columns 1 and 2). Secondly, it seems that a longer duration of time for cooking in women is not associated with an increase probability of chronic or acute diseases or bad self-assessed health, regardless of using random effects probit or random effects ordered probit estimation (see columns 1 and 2). One possible explanation is that perhaps the proximity to cooking stoves really matter health outcomes even with a longer time duration of cooking. More importantly, within a household, house structure/room layout could also significantly affect the substantial spatiotemporal distribution of pollutant concentrations (Zhang and Smith, 2007). Third, it is evident that, although the impact of cooking time on chronic/acute disease or self-reported health might be nonlinear, yet insignificant.

Table 4 Random-effects probit/random-effects ordered probit estimates for household cooking fuels on women health in rural area: CHNS 1991-2009

Variables	Chronic/acute disease (1) Random effects probit	Self-reported health (2) Random effects ordered probit
Coal	-0.063	0.015
	(0.045)	(0.034)
LNG	-0.076	0.124***
	(0.059)	(0.040)
1≤TSC<2 hours/day	0.017	-0.037
	(0.054)	(0.035)
2≤TSC<3 hours/day	-0.057	0.004
	(0.059)	(0.041)
TSC≥3 hours/day	-0.039	-0.078
	(0.063)	(0.051)
N	10871	7696

Note: The dependent variable is a dummy variable of whether the respondent has suffered from a chronic or acute disease or a 4-point-scale measure of self-reported health (1=poor, 2=fair, 3=good and 4=excellent). Controls include cooking fuels

(0=wood, 1=coal, 2=liquefied natural gas (LNG), wood/straw as the reference), dummies of time spent cooking (TSC, 1=TSC<1 hour/day, 2=1≤TSC<2 hours/day, 3=2≤TSC<3 hours/day, 4=TSC≥3 hours/day, with group 1 as the reference group), household income (inflated to 2011) and household size. Standard errors are in parentheses, * p < 0.1, ** p < 0.05, *** p < 0.01.

HCF and cardiovascular diseases (CVD)

China is facing a major increase in cardiovascular diseases (Gordon-Larsen et al., 2013; Yan et al., 2012) and that empirical evidence of the possible effects of household cooking fuels on CVD is quite limited (Fullerton et al., 2008). In our analysis of the CHNS data, we note that, relative to wood/straw, coal use for household cooking is associated with an increase in the probability of high blood pressure, levels of systolic blood pressure and diastolic blood pressure among rural women (see column 1, 3 and 4 in Table 5). These results are consistent with those of Baumgartner et al. (2011), suggesting that biomass fuels like coal might lead to CVD. Note, however, that we cannot find any association between LNG and those examined CVD measures with the exception of diastolic blood pressure.

Table 5 Probit/OLS estimates for household cooking fuels on women's cardiovascular diseases in rural area: CHNS

Variables	Probit estimates		OLS estimates	
	(1)	(2)	(3)	(4)
	High blood pressure	Inflammation	Systolic blood pressure	Diastolic blood pressure
Coal	0.021**	0.057	1.452**	1.063**
	(0.011)	(0.037)	(0.617)	(0.385)
LNG	0.019	0.044	0.941	0.931*
	(0.012)	(0.036)	(0.637)	(0.443)
N	13624	1421	13624	13624
Pseudo R^2/ Adj. R^2	0.171	0.049	0.249	0.150

Note: The dependent variable is a dummy variable of whether the respondent has suffered from high blood pressure, or inflammation (1=yes, 0=no) or the levels of systolic blood pressure and diastolic blood pressure. Blood pressure information is available from 1991 to 2009. Controls include dummies of household cooking fuel choices (0=wood, 1=coal, 2=liquefied natural gas, wood as the reference), individual characteristics (including age, education level, marital status, job status, current smoking behaviour and time spent cooking), family characteristics (translog household income and household size), provincial dummies (Liaoning as the reference province) and year dummies (1991 as the reference year). Marginal effects are reported for probit estimates of high blood pressure and inflammation. Community clustered standard errors are in parentheses, * p < 0.1, ** p < 0.05, *** p < 0.01.

HCF and specific symptoms of chronic or acute diseases

Of additional concern is to check how household cooking fuels are associated with some specific symptoms of chronic or acute diseases (see Table 6). Generally, we cannot find any significant association between coal/LNG (taking wood/straw as the referent) and specific disease symptoms with the exception of significantly negative associations with pain and palpitation in the CFPS and diarrhea and eye disease in the CHNS.

Table 6 Probit estimates for domestic cooking fuels on women health (specific symptoms) in rural area: CFPS 2010-2012 & CHNS 1991-2009

Variables	CFPS				
	Fever	Diarrhea	Cough	Pain	Palpitation
Coal	-0.003	0.003	0.003	0.002	0.007
	(0.005)	(0.002)	(0.004)	(0.014)	(0.005)
LNG	-0.0002	-0.001	0.004	-0.027**	-0.009**
	(0.003)	(0.002)	(0.003)	(0.012)	(0.004)
N	13117	11179	13105	13389	13389
Pseudo R^2	0.020	0.050	0.026	0.059	0.071
Variables	CHNS				
	Fever/cough	Diarrhea	Asthma	Eye	Heart/chest pain
Coal	-0.007	0.003	-0.016	-0.003	0.003
	(0.006)	(0.003)	(0.010)	(0.002)	(0.002)
LNG	-0.010	-0.008*	-0.016	-0.004**	0.003
	(0.006)	(0.004)	(0.013)	(0.002)	(0.002)
N	13624	13624	784	10777	13624
Pseudo R^2	0.066	0.067	0.161	0.176	0.152

Note: The dependent variable is a dummy variable of whether the respondent has suffer from fever, diarrhea, cough, asthma, pain, palpitation, eye or heart disease/chest pain (1=yes, 0=no). Controls include dummies of household cooking fuel choices (0=wood/straw, 1=coal, 2=liquefied natural gas, wood/straw as the reference group), individual characteristics (including age, education level, marital status, job status, current smoking behavior, time spent on food preparation and cooking), family characteristics (translog household income and household size), provincial dummies (Liaoning as the reference province in both the CFPS and CHNS) and year dummies (2010 as the reference year in the CFPS and 1991 as the reference year in the CHNS). Village/neighbour or community-level clustered standard errors are in parentheses, * p < 0.1, ** p < 0.05, *** p < 0.01.

5. Conclusions

This analysis of data from the China Family Panel Studies (CFPS) and the China Health and Nutrition Survey (CHNS) examines fuel-based indoor air pollution on women's health in rural China. Our study extends the existing literature by using the most-recent nationally and regionally representative datasets within panel settings. Furthermore, we initially explore how household cooking fuels are related to some aspects of cardiovascular diseases. Our study highlight the following major findings. First, relative to traditional biomass use like wood/straw, those women in the household using liquefied natural gas for cooking are less likely to suffer from chronic or acute diseases whilst more likely to reported better health outcomes, although the magnitudes are relatively small. One possible explanation is that, cooking fuel information in the CFPS and the CHNS is only collected on the primary fuel use in households, though a significant proportion of rural households still consume a mixture of fuels. As highlighted by Zhang and Smith (2007), the average multiple used fuel types are 2.6, thereby making the health assessment associated with different fuels complicated. Second, longer time exposure to cooking is uncorrelated with an increase health burden of rural women who are engaged in domestic cooking. Finally, coal use for cooking, compared with wood/straw, may be associated with an increase in the probability of high blood pressure, levels of systolic blood pressure and diastolic blood pressure, perhaps suggesting that, biomass use, in particular coal domestic consumption, might somewhat be a risk factor for the occurrence of cardiovascular diseases in rural China.

Our study is, however, subjected to certain limitations. Firstly, although we has attempted to solve the issue of endogeneity of domestic household fuels based on a cross-sectional setting. However, more efforts using the special regressor within a panel scenario are promising. In addition, the empirical evidence of the mechanisms through which fuel-based indoor air pollution operate upon individual health remains unclear and therefore further investigations are required to clarify this aspect.[15]

Although our study is suggestive of the potential health benefits related to cleaner fuels like liquefied natural gas among women who act domestic cooking in rural China, yet a rapid shifting from dirty fuels like biomass to liquefied natural gas and other clean fuels are difficult to achieve within a short-term period mainly because affordability and availability of cleaner fuels like gas and electricity is still questionable (see Baumgartner et al., 2012). Considering spatiotemporal variations and complexities of domestic fuel consumption in China, especially rural areas, therefore, a package of different types of improved fuel use,[16] plus more precise

[15] To our knowledge, we just find Bruce et al. (2000) outline some possible mechanisms by which some major domestic pollutants might result in an increase in respiratory and other health problems.

[16] It is also important to note that, as emphasized by Smith (2014), electricity can be also used for solving indoor pollution, and some electric devices like rice cooker have become popular in some developing countries like China, where the production of rice cooker has increased annually more than 20% over 15 years.

monitoring of indoor air pollutants and effective governmental interventions, might be more viable for reducing indoor air pollution and improve health situations in the near future.

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Appendix 1:

Table A1 Descriptive statistics: CFPS 2010-2012

Variables	Observation	Mean	Std. Dev.	Min	Max
Dependent variables					
Chronic/acute disease	13389	0.349	0.477	0	1
Fever	13389	0.022	0.146	0	1
Diarrhea	13389	0.005	0.071	0	1
Cough	13389	0.015	0.122	0	1
Pain	13389	0.158	0.365	0	1
Palpitation	13389	0.033	0.179	0	1
Self-reported health (SRH)					
Poor	13389	0.151	0.358	0	1
Fair	13389	0.155	0.362	0	1
Good	13389	0.174	0.379	0	1
Very good	13389	0.259	0.438	0	1
Excellent	13389	0.262	0.439	0	1
Household cooking fuels					
Wood/straw	13389	0.645	0.479	0	1
Coal	13389	0.105	0.306	0	1
Liquefied natural gas (LNG)	13389	0.251	0.433	0	1
Individual characteristics					
Age	13389	46.041	16.072	16	97
Working status	13389	0.489	0.500	0	1
Education levels					
Illiterate	13389	0.523	0.500	0	1
Primary school	13389	0.218	0.413	0	1
Middle school	13389	0.192	0.393	0	1
High school	13389	0.051	0.220	0	1
Vocation school	13389	0.012	0.108	0	1
University or higher	13389	0.005	0.072	0	1
Marital status	13389	0.834	0.372	0	1
Current smoking	13389	0.039	0.194	0	1
Family characteristics					
Household income (log)	13389	9.872	1.152	0.693	14.253
Household size	13389	4.682	1.915	1	26

Source: China Family Panel Studies 2010 and 2012.

Note: Self-reported health (SRH) is measured a 5-point-scale (1=poor, 2=fair, 3=good, 4=very good and 5=excellent). Household cooking fuels include wood/straw, coal and liquefied natural gas (0=wood/straw, 1=coal, 2=liquefied natural gas (LNG)). Education level is a 6-point scale dummy (1=illiterate, 2=primary school, 3=middle school, 4=high school, 5=vocational school and 6=university or higher). Marital status is measured on a dummy (1=married, 0=others). Working status is a dummy (1=currently employed, 0=currently unemployed), current smoking behaviour is a dummy (1 if the respondent has smoked for the past month, 0 otherwise).

Table A2 Descriptive statistics: CHNS 1991-2009

Variable	Observation	Mean	Std. Dev.	Min	Max
Dependent variables					
Chronic/acute disease	13624	0.116	0.320	0	1
Fever	13624	0.050	0.218	0	1
Diarrhea	13624	0.019	0.137	0	1
Asthma	13624	0.001	0.030	0	1
Headache	13624	0.048	0.213	0	1
Eye	13624	0.005	0.069	0	1
Heart disease	13624	0.009	0.097	0	1
Self-reported health (SRH)					
Poor	7900	0.069	0.253	0	1
Fair	7900	0.331	0.471	0	1
Good	7900	0.486	0.500	0	1
Excellent	7900	0.114	0.318	0	1
Household cooking fuels					
Wood/straw	13624	0.422	0.494	0	1
Coal	13624	0.399	0.490	0	1
Liquefied natural gas (LNG)	13624	0.179	0.383	0	1
Individual characteristics					
Age	13624	46.602	14.225	16	94
Working status	13624	0.703	0.457	0	1
Education levels					
Illiterate	13624	0.311	0.463	0	1
Primary school	13624	0.354	0.478	0	1
Middle school	13624	0.246	0.431	0	1
High school	13624	0.068	0.251	0	1
Vocation school	13624	0.017	0.129	0	1
University or higher	13624	0.004	0.067	0	1
Marital status	13624	0.860	0.347	0	1
Current smoking	13624	0.040	0.195	0	1
Time spent cooking (hours/day)	10871	1.722	0.929	0.017	4.667
Household characteristics					
Household income (log)	13624	9.374	1.014	1.156	13.668
Household size	13624	4.030	1.548	1	13

Source: China Health and Nutrition Survey 1991, 1993, 1997, 2000, 2004, 2006 and 2009.

Note: Self-reported health (SRH) is measured on a 4-point scale (1=poor, 2=fair, 3=good and 4=excellent). SRH is only available from 1997 to 2006. Household cooking fuels include wood, coal and liquefied natural gas (0=wood, 1=coal, 2=liquefied natural gas (LNG)). Education level is a 6-point scale dummy (0=illiterate, 1=primary school, 2=middle school, 3=high school, 4=vocational school and 5=university or higher). Marital status is measured on a dummy (1=married, 0=others). Working status is a dummy (1=currently employed, 0=currently unemployed), current smoking behaviour is a dummy (1 if the respondent currently smokes cigarettes, 0 otherwise).