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Solid fuel use for cooking and its health effects on the elderly in rural China

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Abstract: Indoor air pollution is mainly caused by solid fuel use for cooking in developing countries. Many previous studies focused on its health risks on the children and in specific local area. This paper investigates household energy usage and transition for cooking in rural China and the health effects on the elderly. A national large-scale dataset CHARLS (China Health and Retirement Longitudinal Study) covering 450 villages and communities is employed. Logit regressions were used to quantitatively estimate the effects, after controlling for some factors such as income, demographic and geographical variables. The results robustly show that compared to non-solid fuels, solid fuel use significantly increases the possibility of chronic lung diseases (30%), exacerbation of chronic lung diseases (95%), seizure of heart disease (1.80 times), and decreases self-evaluated health status of the elderly (1.38 times). Thus, it is urgent to improve clean energy access for cooking in rural China.

Keywords: indoor air pollution; household solid fuel; health risks; elderly; rural; China

1. Introduction

Indoor air pollution caused by the use of solid fuel such as coal, straw, and firewood is a challenge for many developing countries. According to China's National Energy Administration, in December 2015, China has provided full electricity access to all residents (National Energy Administration 2015) . The universal access of electricity improves the availability of clean energy. However, in rural areas of China, the proportion of residence that use solid fuel for indoor cooking and heating remains at a high level. The 2010 National Population Census shows that 76% of farmers in China relied on solid fuel as the main cooking energy(Tang & Liao 2014). In this paper, we investigate household energy usage and transition for cooking in rural areas based on large-scale data covering 150 counties in 28 provinces in China. Moreover, such kind of household energy structure is excluded beyond China. The solid fuels are still the main indoor cooking fuel in most developing countries. About 2.4 billion people relied on traditional biomass (fuel wood, charcoal, manure and agricultural residues) as their main source of energy for cooking, heating and lighting (Smith et al. 2004). 60% of resident-consumed energy in developing countries came from solid fuels such as biomass and coal in 2011 (Malla and Timilsina, 2014).

The combustion of solid fuels releases a range of health-damaging pollutants such as PM2.5, PM10, CO, NO_2, black carbon, organic compounds and other carcinogenic substances(Dėdelė & Miškinytė 2016, Wang et al. 2016, Wei et al. 2014), thus causing indoor air pollution (Gorjinezhad et al. 2017) and CO2 emissions (Qu et al. 2016). A study in Ethiopia shows that the NO_2 concentration in households using biomass as cooking fuel is 2.5 times the annual WHO air quality guideline (Kumie et al. 2010). The concentrations of CO and PM 2.5 are significantly higher in household using wood as cooking fuel than using natural gas (Siddiqui et al. 2009). Indoor air pollution caused by combustion of solid fuels (including traditional biomass and coal) is one of the top ten global health risk (WHO 2002). According to the data from World Health Organization, household indoor air pollution due to solid fuel use for cooking leads to 4.3 million premature deathsin 2012 (WHO 2016a). The risk of diseases (acute lower respiratory tract infection, pneumonia, chronic bronchitis, chronic obstructive pulmonary disease and lung cancer) would increase if those substances are breathed into the body (WHO 2002). Women and children are at a greater risk to health, because they are exposed to high levels of household air pollution (Fullerton et al. 2008, Lui et al. 2017, Madureira 2016, Suk et al. 2016). Blood pressure is found to be associated with indoor air pollution among adult women (Baumgartner et al. 2011, Dutta et al. 2011). Agrawal and Yamamoto studied symptoms of preeclampsia/eclampsia in Indian women. Household women using solid fuels bear twice higher likelihood of reporting preeclampsia/eclampsia symptoms (Agrawal & Yamamoto 2015). Lakshmi et al. (2013) and Pope et al. (2010) found still birth rate was higher among women who use solid fuels as cooking fuel. Indoor air pollution caused by combustion of solid fuels is responsible for chronic obstructive pulmonary disease (COPD) in non-smoking women living in rural areas (Ezzati 2005). Some researchers have studied the relationship between children's health and solid fuels. A study carried out in urban slums of Bangladesh shows association between the biomass fuel-using population and respiratory symptoms on children under five years old (Khalequzzaman et al. 2010). The use of solid fuels was associated with increasing of the risk of pneumonia in

children (Dherani et al. 2008). There are some evidences of lower respiratory tract infection in children and indoor air pollution (Smith et al. 2000). Low birth weight is also associated with indoor air pollution from solid fuel use (Epstein et al. 2013, Pope et al. 2010). Many studies focused on the children's health, but there are few articles discussing the relationship between the elder's health and the use of solid fuels.

The World Health Organization estimates that global older population will increase from 900 million in 2015 to 2.1 billion in 2050, 30% of which comes from China (WHO 2016b). According to the China Aging Research Center, there were 202 million elderly people living in China in 2013 (Wu &Dang 2013). The proportion of people over 65 of the whole was 8.2% in 2010 in China, which will reach 30.2% in 2065 (Li &Lin 2016). Population aging is leading to an increase in the incidence of chronic diseases, resulting in reduced economic performance and increased health care public expenditures (Sirven &Debrand 2008). By 2030, the elderly over the age of 45 will bear two-thirds of the total burden of disease in China (Chatterji et al. 2008). Older people are more susceptible to indoor air pollution, even at low concentrations, because (i) elderly people spend more time at home than others, (ii) immunological defense of elderly is reduced and they have multiple underlying chronic diseases (Bentayeb et al. 2013, Mendes et al. 2016). The health of the elderly in rural areas is worse than that of the urban(Liu et al. 2017, Ma et al. 2017). Previous research of the elderly focus on morbidity, influencing factors and gender differences (Liu et al. 2016, Wang et al. 2017, Wu &Ouyang 2017, Zhang et al. 2017), but rarely consider the use of cooking fuel. Researches on health and fuel in the elderly are limited by certain diseases and confined to individual regions in several provinces (Agrawal &Yamamoto 2015, Liu et al. 2007, Peabody et al. 2005, Qu et al. 2015). Our study focuses on the disease and overall health of the elderly in rural area and covers 28 provinces and regions in China.In this paper, we evaluate the health of the elderly in terms of the diagnosis of disease, comparison of health status, and self-assessment of health status and explore the impact of fuel on health based on the logit model. On this basis, we further study the impact of solid fuel uses on disease exacerbation and seizure. Previous studies analyze mostly from the perspective of environmental science and engineering, focusing on natural science mechanism and conduction mechanism of health, using the method of controlled experiment. But in reality, it is difficult to control the experimental conditions and the acquisition of large sample is costly. The controlled experiment can only be analyzed for areas and cannot be carried out at the national level. Since the large regional differences in China, the conclusion of local areas is hardly able to represent the average conclusion of the country. Therefore, we analyze the facts and behaviors directly observed and focus on socioeconomic factors, including income, gender, and so on, which also facilitate the use of nationwide large-scale sampling data.

2. Data sources and descriptions

2.1 Data Sources

All the data used in this study is sourced from China Health and Retirement Longitudinal Study (CHARLS). This is a survey for middle-aged and elderly people in China. The interviewees were people aged 45 years old or more from randomly-selected families. The

CHARLS survey selected 450 villages or communities in 150 counties of 28 provinces across the country using Probability Proportionate to Size Sampling. They are the representatives of China to a large extent. The questionnaire consists of eight modules and covers four levels of individual, family, community, macroeconomic policy, and can meet the research needs of a variety of disciplines at the same time. There are both self-reported health status and objective health indicators, which is conducive to the study of the health of the elderly. For our research purpose, we have selected some variables from the data-set where the missing and abnormal values have been deleted because of inconsistencies. For more details about CHARLS, please visit http:// http://charls.pku.edu.cn/.

We use data from the CHARLS 2011 baseline survey and the 2013 follow-up survey only. CHARLS questionnaire divides the cooking fuels into seven sub-groups: "coal", "natural gas", "biogas", "liquefied petroleum gas (LPG)", "electricity", "biomass", and "others". In this paper, "coal" is combined with "biomass", both of which are regarded as "solid fuel" in brief. The "natural gas (NG)", "biogas", liquefied petroleum gas (LPG)" and "electricity" are categorized as modern clean energy. The group "Others" (account for 0.79% in 2011, 0.75% in 2013) is excluded because of its characteristic of non-classification.

There are some limitations with CHARLS when investigating the solid fuel issues. The questionnaire is not designed specifically for investigating residents' fuel choice. We endeavor to select appropriate variables. In the questionnaire, the diseases are simply classified. Heart attack, coronary heart disease, angina, congestive heart failure and other diseases are combined as heart problems, although they are not all related to the use of solid fuels. When about it comes to chronic lung disease, a similar situation has occured. Fortunately, CHARLS has a large sample, which facilitate us to use statistical and econometric tools to address these difficulties. And we will see that most of the important results are statistically significant and robust.

2.2 Fuel use and transition

Households in China are still highly dependent on solid fuels. Nearly half of households use solid fuels as the main cooking fuel. The column/row of Total in Fig. 1 shows the proportions of households by cooking fuel choice in 2011/2013.The proportion of households using coal and biomass as main cooking fuel are 11% and 45% in 2011 respectively, which are 9% and 38% in 2013. Electricity is the most widely used clean energy. Households using electricity as their main cooking fuel accounts for 17% in 2011, which increases to 22% in 2013. This may be due to that electricity is available in most areas in China. Despite the government has invested more than 19 billion CNY in the rural biogas project since 2003 (Gao et al. 2009), biogas is still seldom used in China. Only about 1% of households use biogas as the main cooking fuel.

Comparing the status of fuel use in 2011 and 2013, we find that the use of solid fuels as the main cooking fuel is decreasing. The proportion of households using biomass as the main cooking fuel falls from 45% to 38%. The proportion of households using coal as the main cooking fuel also falls by two percentage points. The proportions of households using a

variety of clean energy excluding biogas are increasing. The main cooking fuel for households is undergoing a transition from solid fuel to clean energy.

Nearly 40% of the households change their main cooking fuel between the year 2011 and 2013, but the direction of transition is uncertain. As shown in Fig.1, 15% of households opted to use clean energy for solid fuels, while 7% of households go back to solid fuels. 40% of the households used solid fuel as their main cooking fuel in 2011, and continued to use solid fuel in 2013. 1.2%, 0.7% and 2.1% of the households that once used coal in 2011 turned to, LPG, natural gas and electricity for cooking in 2013, respectively. 0.4%, 2.8%, 1.9% and 6.3% of the households that once used biomass in 2011 turned to biogas, LPG, natural gas and electricity for cooking in 2013, respectively. In general, the proportion of households transitioned to clean energy is greater than that transitioned to solid fuels. Main cooking fuels appear to be shifting towards electricity. 13% of households give up other fuels and choose electricity as the main cooking fuel.

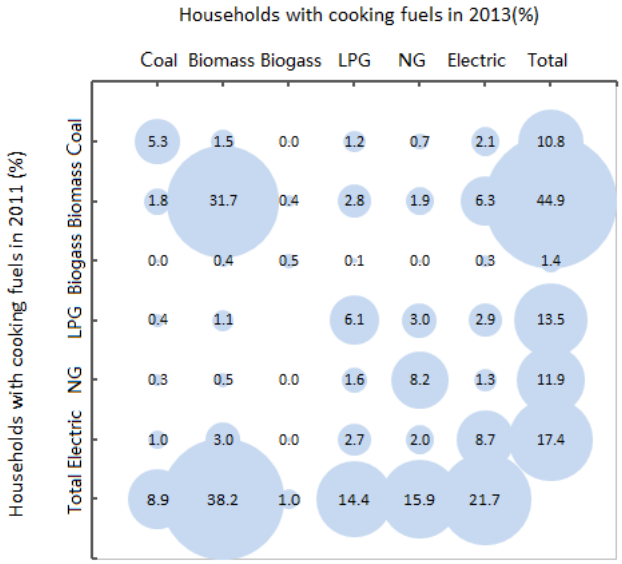
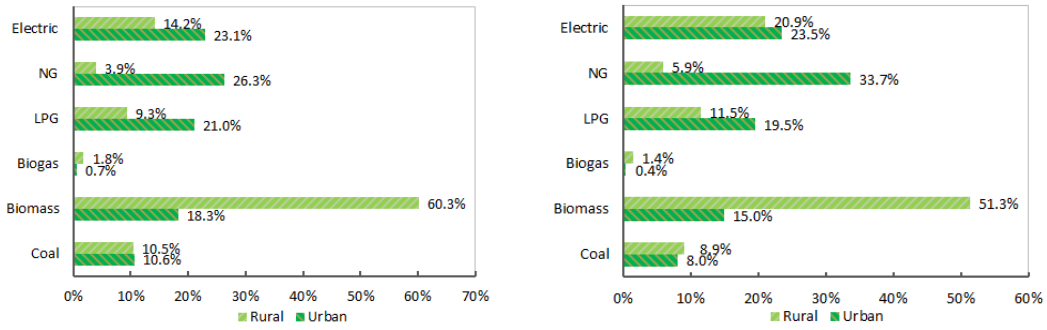


Fig.1 The main cooking fuels transition from 2011 to 2013 in China.

Notes: The data was obtained by CHARLS from 8694 households. The abscissa and ordinate represent various cooking fuels used by households in 2013 and 2011, respectively. The data shows the percentage of households using certain kinds of fuels in the total number of households in 2011 and 2013. The bubble size varies in proportion to the percentage.

There is a rural-urban gap in fuel use. Households in urban areas are used to employing clean energy as the main cooking fuel, while rural households prefer to use solid fuels. As shown in Fig.2, in 2011, more than 70% of rural households use solid fuel, while in stark contrast, more than 70% of households rely on clean energy as main cooking fuel in urban areas. The most commonly used fuel is natural gas in urban areas. This may be explained by

the continuous improvement of urban infrastructure construction of natural gas. Rural households are still strongly dependent on biomass. One possible reason might be that biomass can be collected everywhere and without any charge.



a) 2011 b) 2013

Fig.2 Household distribution by cooking fuel type.

Notes: The data was obtained by CHARLS from 9985 households in 2011, and 10586 households in 2013. The ordinate represents the different fuel types. The abscissa represents the percentage of households using certain type of fuels.

Considering the rural-urban gap, we analyze the transition in rural areas separately. Fig. 3 displays the transition matrix from 2011 to 2013 in rural areas. The household energy transition is significant in rural China. 14% of the rural households that used biomass in 2011 chose clean energy in 2013. 3% of the rural households that used coal in 2011 chose clean energy in 2013. In other words, one quarter of the households that used solid fuels in 2011 transfer their main cooking fuel to clean energy. 14% of households converted their main cooking fuel to electricity. Electricity is also the main direction of transition in rural areas, followed by LPG.

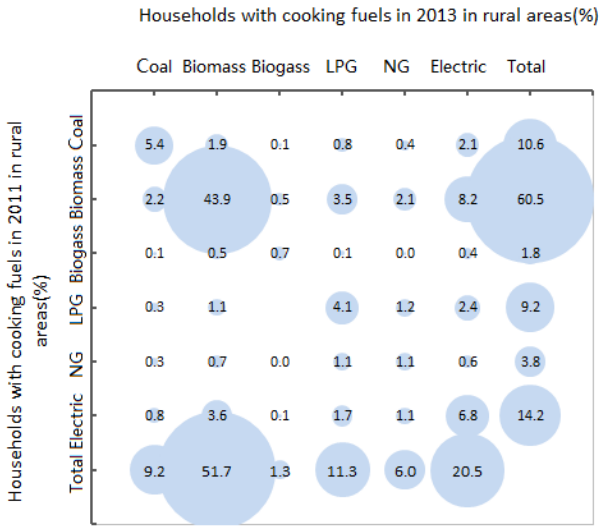


Fig.3 The main cooking fuels transition from 2011 to 2013 in rural China.

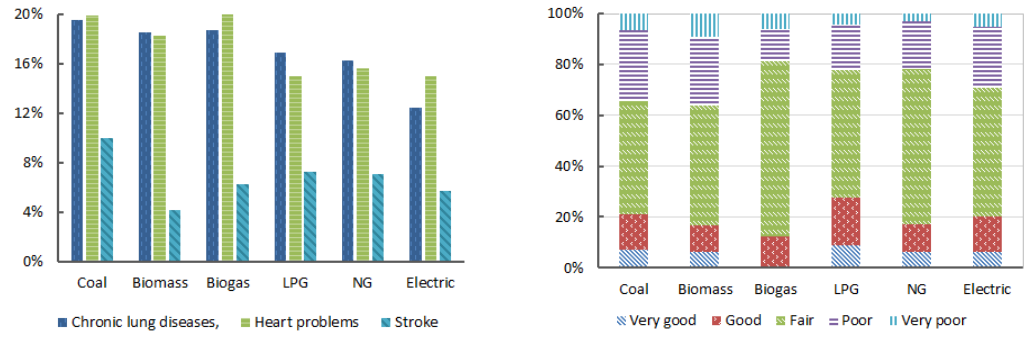
Notes: The data was obtained by CHARLS from 5384 households in rural areas. The abscissa

and ordinate represent the various cooking fuels used by rural households in 2013 and 2011, respectively. The data shows the percentage of households using certain kinds of fuels in the total number of households in 2011 and 2013. The bubble size varies in proportion to the percentage.

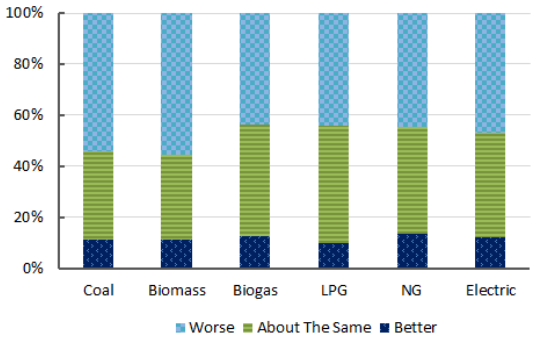
2.3 Fuel, health and income

The foregoing analysis shows that solid fuel is still widely used as main cooking fuel in rural areas in China, although there has been a trend of transition from solid fuel to clean energy. Combustion of solid fuels releases a large quantity of pollutants such as particulate matter, CO, NO_2, organic compounds causing serious indoor air pollution and finally leading to serious health damage. The elderly suffer from health risk since they usually spend more time on indoor activities. We use different methods to measure the health of residents. Sickness diagnosed by a doctor is a relatively objective indicator to describe the health status. According to the World Health Organization Report, indoor air pollution leads to 3.8 million premature deaths annually from pneumonia, stroke, ischemic heart disease, chronic obstructive pulmonary disease and lung cancer (WHO 2016a). Combing the questions about sickness in CHARLs questionnaire, we select chronic lung disease (such as chronic bronchitis, emphysema), heart disease, and stroke as relatively objective indicators. We also choose two subjective health indicators: self-assessment of health status and comparison of health status. Self-assessment of health status represents the own assessment of residents. In the questionnaire, the assessment of health status is divided into five grades: very good, good, fair, poor, very poor. Comparison of health status represents that, compared with 2011, what changes occurred in health status in 2011.

Residents relying on solid fuel for cooking have inferior health compared to those using clean energy. As shown in Fig.4 a) the proportion of residents with chronic lung diseases is higher when solid fuel is their main cooking fuel. So does the proportion of residents with heart diseases. Residents using biogas are anomalous, because the sample size is too small. Fig.4 b) shows that nearly 40% of the residents who use solid fuel as main cooking fuel consider that they have "poor" or "very poor" health, which is less than 30% for group using clean energy. Fig.4 b) shows that more than half residents who use solid fuel as main cooking fuel consider that they have "worse" health than the year 2011.



a) diseases b) self-assessment of health status

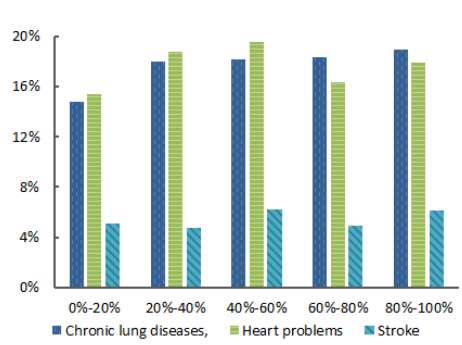


c) comparison of health status

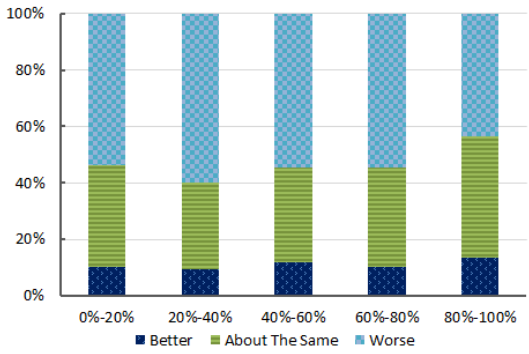
Fig.4 The health status of residents by cooking fuel type.

Notes: The data was obtained by CHARLS2013 from 2590 residents over 65 years old in rural areas. The abscissa represents the different fuel types. The ordinate in a) represents the percentage of residents diagnosed by a doctor. The ordinate in b) and c) represent the proportion of each grades of health status.

Residents with higher income have better health status. For simplicity, we divide the household per capita income by five quantiles. As shown in Fig.5, higher income and sickness diagnosed by a doctor do not necessarily correlate. The higher the income, the smaller the proportion of residents who consider they have "poor" and "very poor" health (see Fig.5 b). As Fig. 5 c) shows, among the top 20 percent of the residents, the proportion of residents who consider that they have "worse" health than the year 2011 is the lowest.



a) diseases b) self-assessment of health status



c) comparison of health status

Fig.5 The health status of residents by income quantile.

Notes: The data was obtained by CHARLS2013 from 2590 residents over 65 years old in rural areas. The abscissa represents the different income levels. The ordinate in a) represents the percentage of residents diagnosed by a doctor. The ordinate in b) and c) represent the proportion of each grades of health status.

3. Method

Three sets of dependent variables, namelySickness diagnosed by doctor, Self-assessment of health status and Comparison of health status, are selected to measure the health of the elderly as comprehensively as possible.

Sickness diagnosed by doctor: As discussed above, we select three diseases: we select chronic lung disease (such as chronic bronchitis, emphysema), heart disease, and stroke. When diagnosed with a disease, the value of the variable is assigned to 1, otherwise equal to 0.

Self-assessment of health status: This variable represents assessment of health status. The value of the variable is assigned to 1, if the resident evaluates their health status as “poor”, otherwise equal to 0.

Comparison of health status: This variable represents that, compared with 2011, what changes occurred in health status in 2011. The value of the variable is assigned to 1, if the resident think their health status become “worse” compared with the year 2011, otherwiseequal to 0.

These dependent variables, self-assessment of health status and comparison of health status, are set to explore the impact of solid fuels on the overall health of the elderly. The dependent variable of sickness diagnosed by a doctor is set to explore the effects of solid fuel on the prevalence of the elderly. In order to study how the use of solid fuels affects the disease of the elderly, the samples are classified according to whether the disease is diagnosed. For the elderly who have been diagnosed with the disease before 2011, we also discuss the effects of solid fuels on disease exacerbation and seizure. (Considering the clinical symptoms of chronic lung diseases, the discussion of its seizure makes no sense.) Disease exacerbation is

a subjective health indicator. Seizure is relatively objective health indicator. For the elderly who have not been diagnosed with the disease before 2011, we discussed the impact of solid fuels on the diagnosis of the disease after 2011.

Exacerbation: For the elderly who have been diagnosed with the disease before 2011, the variable is assigned to 1 if the residents thought their disease exacerbated, otherwise equal to 0.

Seizure: For the elderly who have been diagnosed with the disease before 2011, the variable is assigned to 1 if the disease seizure, otherwiseequalto 0.

The latest diagnosis: For the elderly who have not been diagnosed with the disease before 2011, the variable is assigned to 1 if the disease is diagnosed after 2011, otherwise equal to 0.

Since the explanatory variables in our study are binary， the binary logit model is applied as the basic model. The advantage of the logit model is that the problem of predicting the probability on the interval is transformed into the prediction of odds on the real axis. The cumulative logistic probability function is applied in logit model. In binary logistic regression, the probabilities are modeled as follows (Stock & Watson 2002):

$$\mathrm{P}(\mathrm{Y}_i = 1) = \mathrm{P}_i = \frac{e^{X_i\beta}}{1+e^{X_i\beta}} \tag{1}$$

$$\mathrm{P}(\mathrm{Y}_i = 0) = 1 - \mathrm{P}_i = \frac{1}{1+e^{X_i\beta}} \tag{2}$$

Where, i denotes the i-th observation, $\mathrm{P_i}$ denotes the probability, $\mathrm{X_i}$ denotes the independent variables, and β denotes the model coefficient. The coefficients are estimated using the method of maximum likelihood estimation. The likelihood function is of this form:

$$\mathrm{L} = \prod_{i=1}^{n} P_i^{y_i}(1 - P_i)^{1-y_i} \tag{3}$$

The logarithmic likelihood function is

$$\ln L = \sum_{i=1}^{n} y_i P_i + \sum_{i=1}^{n}(1 - y_i)(1 - P_i) \tag{4}$$

After computing the derivatives of this log likelihood with respect to β and equating to zero, we can get the estimated value of β. The estimated result of the coefficient represents the logarithm of odds. It means that the ratio of $\mathrm{P(Y_i=1)}$ to $\mathrm{P(Y_i=0)}$ is e^{β}.

The estimation model we apply is of the form:

$$\ln\left(\frac{P_y}{1-P_y}\right) = \beta_0 + \beta_1 fuel + \beta_2 Ln\ income + \beta_3 age + \beta_4 female + \beta_5 smoke + \beta_6 drink + \beta_7 sleepingtime + \beta_8 kitchen + \beta_9 tapwater + \beta_{10} topography + \mu \tag{5}$$

P_y represents the probability that the variable y is interpreted. μ is the error term. Fuel is explanatory variable. There are nine controllable variables: income, age, female, smoke, drink, sleeping time, kitchen, tap-water and topography.

Fuel: Solid fuel use is associated with increased health risks for many diseases, and leads to premature death. When solid fuel is used as main cooking energy, the variable is assigned to 1, otherwise equal to 0.

Income: This variable represents the household per capita income. Higher income means better access to health care. Higher household incomes are associated with better health in all countries (Mackenbach et al. 2005).

Age: Age will affect the health of the elderly. With the increase of age, the immunological defense function decreases and the probability of suffering from various diseases increases (Bentayeb et al. 2013, Mendes et al. 2016). Age is limited to over 65.

Gender: Women are the main perpetrators of cooking activities and fuel collection. Women are at greater risk to health, because they are exposed to high levels of indoor air pollution (Fullerton et al. 2008). So, gender is associated with health problems caused by indoor air pollution. When the resident is a female, the gender is set to 1.

Smoke: This variable indicates whether the resident has had the habit of smoking, now or in the past. If so, the variable is assigned to 1, otherwise equal to 0.

Drink: This variable indicates whether the resident has had the habit of drinking, now or in the past. If so, the variable is assigned to 1, otherwiseequal to 0.

Sleeping time: This variable represents hours of actual sleep at night and nap after lunch.

Kitchen: In some households in rural China, there are no separate kitchens for the reason that they are used to sleeping, meeting, and cooking in the same room. Separate kitchen can effectively prevent the spread of indoor air pollution. A study in China finds that separate kitchen and reduction of indoor PM pollution are significantly correlated (Gao et al. 2009). Mishra (2003) found that separate kitchens were associated with lower asthma prevalence. The variable is assigned to 1 when there are separate kitchens, otherwise equal to 0.

Tap-water: The safety of drinking-water affects is associated with health risks. Many households have not gained access to an improved drinking-water source such as tap-water. The variable is assigned to 1 when tap-water is accessible, otherwise equal to 0.

Topography: This variable is an unordered categorical variable that represents the main topography of the village. The topography is divided into five categories: plain, hill, mountainous region, plateau and basin.

4. Results and discussions

Table 1 presents the results. Age will affect the health of the elderly, but the results show that the regression coefficient is very small. The results of gender show that older women do not have higher health risks due to cooking activities. For older male, the risk of chronic lung disease significantly increases. This is contrary to the results of research for young women (Fullerton et al. 2008). The results of age and gender suggest that previous studies on the relationship of indoor air pollution and health may not apply to the elderly. Researches for the elderly are necessary and urgent.

The use of solid fuels as the main cooking fuel has a negative impact on the health of the elderly. Table 1 presents the results. In the case of using solid fuels, the relative possibility of catching chronic lung diseases increase by 30% [=exp(0.26)-1] when compared with that of using clean energy, after controlling other variables. The stroke effect of solid fuel using is not statistically significant, which will be explained later. In the case of using solid fuels, the probability of deterioration in health is 1.36 [=exp(0.31)] times that of clean energy, and the possibility of decrease of health evaluation is 1.38 [=exp(0.32)] times that of clean energy.

The impact of income on the overall health status of the elderly is negative and significant. The results suggest that better economic conditions are conducive to preventing the health of the elderly from deterioration and make the elderly more optimistic about their health status. However, the impact of income on the risk of chronic lung diseases, heart problems and stroke is opposite but insignificant, possibly because the income of the elderly in rural areas is quite low, and that only the better-off old people can afford the fee for diagnosis, while the poor elderly cannot. If the income of all the elderly in rural areas increases, we may obtain similar findings like others.

The habits of the elderly have a significant impact on their health. The risks of diseases of the elderly who drink are obviously higher than those who never drink. For the elderly who drink, the risk of stroke should increase by 127% [=exp(0.82)-1]. Drinking is also considered to be associated with poor health status and deterioration of health. Sleeping time has a positive impact on the health. Longer sleep time is associated with lower disease risks and better health status. Smoking can lead to a significant increase in the risk of chronic lung diseases.

Different from the previous studies, our results show separate kitchens have a negative impact on the health of the elderly. In rural China, the majority of young people work in cities or towns as migrant laborers all year round. The elderly is forced to be the main bearers of the cooking activities. Meanwhile, due to the lack of kitchen exhaust fan and range hood in rural areas， separate kitchen increased the risk of exposure. Thus, separate kitchens do not play a role in isolating the elderly from the source of pollution, leading to negative effects on the health of the elderly.

Safety tap-water is associated with lower risks of diseases and better health status. Topography is associated with the risk of heart problems. The elderly in the plains are at

higher risk for heart problems.

Table 1. Results of logit model estimates for the elderly in rural China

Variables	(1)	(2)	(3)	(4)	(5)
	Diagnosed by doctor			Self-assessment of health status	Comparison of health status
	Chronic lung diseases	Heart problems	Stroke		
Fuel (solid =1)	0.26*	0.23	-0.15	0.32***	0.31***
	(0.15)	(0.14)	(0.25)	(0.12)	(0.11)
Ln income	0.05	0.02	0.01	-0.13***	-0.11***
	(0.04)	(0.04)	(0.07)	(0.03)	(0.03)
Age (≥65)	0.01	-0.01	0.00	0.02**	0.01*
	(0.01)	(0.01)	(0.02)	(0.01)	(0.01)
Gender (female=1)	-0.37**	0.26	-0.33	0.16	-0.07
	(0.16)	(0.16)	(0.28)	(0.13)	(0.12)
Smoke (Yes=1)	0.30**	0.08	-0.13	-0.05	0.04
	(0.15)	(0.15)	(0.27)	(0.13)	(0.12)
Drink (Yes=1)	0.24*	0.24*	0.82***	0.35***	0.09
	(0.12)	(0.12)	(0.21)	(0.10)	(0.10)
Sleeping time (hours/day)	-0.02	-0.05**	-0.09**	-0.08***	-0.05***
	(0.02)	(0.02)	(0.03)	(0.02)	(0.01)
Kitchen	0.15	0.09	0.73*	0.03	0.04
	(0.18)	(0.18)	(0.40)	(0.14)	(0.13)
Tap-water	-0.21*	-0.12	-0.30	-0.10	-0.21**
	(0.12)	(0.12)	(0.21)	(0.10)	(0.09)
Topography (plain =1)					
Hill	0.18	-0.20	-0.24	0.10	0.10
	(0.14)	(0.13)	(0.25)	(0.12)	(0.11)
Mountainous	0.18	-0.45***	0.04	0.41***	0.18
	(0.16)	(0.16)	(0.26)	(0.13)	(0.12)
Plateau	0.18	-0.65**	-0.60	0.71***	-0.14
	(0.28)	(0.31)	(0.62)	(0.22)	(0.22)
Basin	0.23	-0.91**	-0.20	-0.08	-0.00
	(0.29)	(0.38)	(0.55)	(0.26)	(0.23)
Obs.	2,252	2,252	2,252	2,198	2,244

Notes: ***, **, and * indicate statistical significance at 1, 5, and 10%. Fuel, female and smoke, drink, kitchen and tap-water are dummy variables. Income represents the household per capita income. The topography is divided into five categories: plain, hill, mountainous region, plateau and basin. The table shows the results of comparison with plain.

Table 2 shows the results that samples classified according to whether the disease is diagnosed before 2011. It is found that the effect of solid fuel on chronic lung disease is manifested in the exacerbation of the disease. The impact of solid fuel on heart problems is reflected in an increase risk in seizure. Columns (1) to (3) are estimates of disease

exacerbation of the elderly who have been diagnosed with the disease in 2011. The results show that solid fuel can lead to exacerbation of the diseases, especially chronic lung diseases. That means, in the case of using solid fuels, the relative possibility of exacerbation of chronic lung diseases increased by 95% [=exp(0.67)-1] when compared with using clean energy. Column (4) shows that the use of solid fuels has a negative significant impact on the seizure of heart disease. For the elderly who have been diagnosed with heart disease, the probability of seizure of heart disease when using solid fuels is 1.80 [=exp(0.59)] times that of using clean energy. For the elderly who have not been diagnosed with chronic lung disease before 2011, the use of solid fuels increases the risk of chronic lung diseases insignificantly. The result of heart problems in column (7) is similar. Solid fuel use hardly increases the risk of heart problems for the elderly without heart disease before 2011. But for the elderly who have not been diagnosed with stroke, the impact of solid fuel use on stroke is positive and insignificant. This interesting result will be discussed separately.

All estimates of stroke were statistically insignificant. There may be two reasons: (i) the results are statistically insignificant due to the small sample size. The sample size is only 80 in column 3 in Table 2. (ii) the mortality rates from stroke is relatively high. A high mortality rate results in many stroke patients exiting the questionnaire due to death. The majority of the samples are surviving stroke patients, which may be the reason for the strange results appearing.

The results of effect of solid fuel use on the disease obtained in this paper are generally underestimated. The formation of these chronic diseases is not within a year or two, but long-term accumulation. There are potential patients who are not diagnosed currently. In the last few decades, most of the households' fuel choices have been gradually shifted from solid fuels to clean energy. It means that a majority of the households using clean energy currently used solid fuels in the past. Patients from these households are sometimes still plagued by early use of solid fuels.

Table 2. Results of logit model estimates for data classified by diagnostic time

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Exacerbation			Seizure		The latest diagnosis		
	Chronic lung diseases	Heart problems	Stroke	Heart problems	Stroke	Chronic lung diseases	Heart problems	Stroke
Fuel (solid =1)	0.67*	0.29	-0.07	0.59*	1.81	0.17	0.16	-0.33
	(0.36)	(0.39)	(0.92)	(0.33)	(1.25)	(0.39)	(0.32)	(0.56)
Ln income	-0.01	-0.23**	0.00	-0.01	0.37	0.02	-0.12	0.05
	(0.09)	(0.11)	(0.31)	(0.09)	(0.42)	(0.11)	(0.09)	(0.17)
Age≥65)	0.01	-0.04	0.04	-0.01	0.00	0.03	-0.02	0.01
	(0.02)	(0.03)	(0.08)	(0.03)	(0.09)	(0.03)	(0.02)	(0.04)
Gender (female=1)	-0.12	0.17	0.58	0.40	3.34**	-0.87**	0.67*	-0.21
	(0.34)	(0.39)	(0.98)	(0.35)	(1.56)	(0.44)	(0.34)	(0.66)
Smoke	0.00	-0.44	1.22	0.55	3.89**	0.08	0.39	0.34
	(0.34)	(0.38)	(1.02)	(0.34)	(1.78)	(0.41)	(0.34)	(0.65)
Drink	0.17	0.29	0.75	0.29	1.39	0.16	0.49*	0.42
	(0.26)	(0.33)	(0.81)	(0.28)	(0.97)	(0.33)	(0.27)	(0.49)
Sleeping time (hours/day)	0.01	-0.04	-0.07	-0.13***	-0.08	-0.06	-0.05	-0.07
	(0.04)	(0.05)	(0.13)	(0.04)	(0.16)	(0.05)	(0.04)	(0.08)
Kitchen	0.02	0.90	-0.87	-0.21	-3.97**	-0.08	-0.47	0.22
	(0.40)	(0.57)	(1.35)	(0.40)	(1.82)	(0.45)	(0.32)	(0.76)
Tap-water	0.14	-0.37	-1.85**	0.30	-0.52	0.32	-0.00	-0.89*
	(0.26)	(0.30)	(0.86)	(0.26)	(0.92)	(0.34)	(0.26)	(0.49)
Topography (plain =1)								
Hill	-0.42	-0.02	-0.85	-0.32	-0.82	-0.29	-0.50*	-0.76
	(0.32)	(0.32)	(0.99)	(0.29)	(1.01)	(0.37)	(0.30)	(0.64)
Mountainous	-0.01	-0.83*	-0.63	-0.52	-4.66**	-0.57	-0.43	0.14
	(0.33)	(0.45)	(0.95)	(0.35)	(2.00)	(0.44)	(0.32)	(0.57)
Plateau	-0.15	-0.77		-0.51		0.62		-0.04
	(0.65)	(0.83)		(0.66)		(0.54)		(1.09)

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Exacerbation			Seizure		The latest diagnosis		
	Chronic lung diseases	Heart problems	Stroke	Heart problems	Stroke	Chronic lung diseases	Heart problems	Stroke
Basin	-0.40	-0.89		-1.33	0.09		-1.32	-0.05
	(0.63)	(1.12)		(1.12)	(2.82)		(1.03)	(1.09)
Obs.	347	315	80	315	83	1,835	1,847	2,167

Notes: ***, **, and * indicate statistical significance at 1, 5, and 10%. Fuel, female and smoke, drink, kitchen and tap-water are dummy variables. Income represents the household per capita income. The topography is divided into five categories: plain, hill, mountainous region, plateau and basin. The table shows the results of comparison with plain. Columns (1) to (3) and (4) to (5) are estimates of disease exacerbation and seizure of the elderly who have been diagnosed with the disease in 2011. Columns (6) to (8) are estimates of disease diagnosed between 2011 and 2013.

5. Conclusions and implications

5.1 Households in rural China still heavily rely on solid fuels.

Although there has been a trend turning fromsolid fuels to clean energy, 60% of the rural people mainly rely on solid fuels for cooking. Among the households using solid fuels as main cooking fuel in 2011, the proportion of transition to clean energy is as high as 25%. However, 15% of the households that use non-solid fuels for cooking turned to the solid during 2011-2013.

5.2 Solid fuel results in negative health effects on the elderly in rural China

Solid cooking fuel has a negative impact on the elder's health. In the control of other factors such as smoking and drinking, the use of solid fuel could lead to an increase of 30% in the risk of chronic lung diseases, an increase of 95% in the possibility of exacerbation of chronic lung diseases when compared with using clean energy. For the elderly who have been diagnosed with heart diseases, the probability of seizure of heart disease when using solid fuels is 1.80 times that of using clean energy. In the case of using solid fuels, the probability of deterioration of health is 1.36 times that of clean energy, the possibility of decrease of health evaluation is 1.38 times that of clean energy. The results on gender are inconsistent and insignificant. We do not find that older women have higher health risks due to cooking activities.

5.3 Policy implications

The elderly in rural areas in China have low income levels and poor living conditions. The results of the existing studies can not be applied to them. So it is necessary to conduct researches specifically for the elderly. It is conducive to the formulation and implementation of government welfare policies, especially when China is stepping into aging society.

In order to reduce the health risks caused by the use of solid fuels, the promotion of clean energy is necessary. Firstly, as of December 2015, 100% of China’s residence have the electricity access, but some households still never use electricity as cooking fuel because of poverty, habits, lack of electric cookers and so on. The government should continue to promote the use of electricity as cooking fuels through subsidies and popularize of electric cookers. Second, the promotion of biogas in China is not as satisfactory as expected. Many of the household-scaled biogas digesters are poorly run or even deserted because of China's climate, farmers' low technical knowledge and other issues (Jiang et al. 2011, Ling et al. 2012). Therefore, the promotion of clean energy in rural areas should also focus on natural gas or liquefied petroleum gas (LPG) after considering the local geographic and resource conditions.

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References

Agrawal S, Yamamoto S (2015): Effect of Indoor air pollution from biomass and solid fuel combustion on symptoms of preeclampsia/eclampsia in Indian women. Indoor Air 25, 341-52

Baumgartner J, Schauer JJ, Ezzati M, Lu L, Cheng C, Patz JA, Bautista LE (2011): Indoor Air Pollution and Blood Pressure in Adult Women Living in Rural China. Environmental Health Perspectives 119, 1390-5

Bentayeb M, Simoni M, Norback D, Baldacci S, Maio S, Viegi G, Annesi-Maesano I (2013): Indoor air pollution and respiratory health in the elderly. Journal of Environmental Science & Health Part A Toxic/hazardous Substances & Environmental Engineering 48, 1783-9

Chatterji S, Kowal P, Mathers C, Naidoo N, Verdes E, Smith JP, Suzman R (2008): The health of aging populations in China and India. Health Affairs 27, 1052-1063

Dedele A, Miskinyte A (2016): Seasonal variation of indoor and outdoor air quality of nitrogen dioxide in homes with gas and electric stoves. Environmental Science & Pollution Research 23, 17784-17792

Dherani M, Pope D, Mascarenhas M, Smith KR, Weber M, Bruce N (2008): Indoor air pollution from unprocessed solid fuel use and pneumonia risk in children aged under five years: a systematic review and meta-analysis. Bulletin of the World Health Organization 86, 390

Dutta A, Mukherjee B, Das D, Banerjee A, Ray MR (2011): Hypertension with elevated levels of oxidized low-density lipoprotein and anticardiolipin antibody in the circulation of premenopausal Indian women chronically exposed to biomass smoke during cooking. Indoor Air 21, 165-176

Epstein MB, Bates MN, Arora NK, Balakrishnan K, Jack DW, Smith KR (2013): Household fuels, low birth weight, and neonatal death in India: the separate impacts of biomass, kerosene, and coal. International Journal of Hygiene & Environmental Health 216, 523-532

Ezzati M (2005): Indoor air pollution and health in developing countries. Lancet 366, 104-106

Fullerton DG, Bruce N, Gordon SB (2008): Indoor air pollution from biomass fuel smoke is a major health concern in the developing world. Transactions of the Royal Society of Tropical Medicine & Hygiene 102, 843-851

Gao X, Yu Q, Gu Q, Chen Y, Ding K, Zhu J, Chen L (2009): Indoor air pollution from solid biomass fuels combustion in rural agricultural area of Tibet, China. Indoor Air 19, 198-205

Gorjinezhad S, Kerimray A, Torkmahalleh MA, Keleş M, Ozturk F, Hopke PK (2017): Quantifying trace elements in the emitted particulate matter during cooking and health risk assessment. Environmental Science & Pollution Research 24, 1-15

Jiang X, Sommer SG, Christensen KV (2011): A review of the biogas industry in China. Energy Policy 39, 6073-6081

Khalequzzaman M, Kamijima M, Sakai K, Chowdhury NA, Hamajima N, Nakajima T (2010): Indoor air pollution and its impact on children under five years old in Bangladesh. Indoor Air 17, 297-304

Kumie A, Emmelin A, Wahlberg S, Berhane Y, Ali A, Mekonnen E, Brandstrom D (2010): Magnitude of indoor NO2 from biomass fuels in rural settings of Ethiopia. Indoor Air 19, 14-21

Lakshmi PV, Virdi NK, Sharma A, Tripathy JP, Smith KR, Bates MN, Kumar R (2013): Household air pollution and stillbirths in India: analysis of the DLHS-II National Survey. Environmental Research 121, 17-22

Li S, Lin S (2016): Population aging and China's social security reforms. Journal of Policy Modeling 38, 65-95

Ling C, Zhao LX, Ren CS, Fei W, Martinot E, Zhang X (2012): The progress and prospects of rural biogas production in China. Energy Policy 51, 58-63

Liu GG, Xue X, Yu C, Wang Y (2016): How does social capital matter to the health

status of older adults? Evidence from the China Health and Retirement Longitudinal Survey. Economics & Human Biology 22, 177-189

Liu H, Byles JE, Xu X, Zhang M, Wu X, Hall JJ (2017): Evaluation of successful aging among older people in China: Results from China health and retirement longitudinal study. Geriatrics & gerontology international 17, 1183-1190

Liu S, Zhou Y, Wang X, Wang D, Lu J, Zheng J, Zhong N, Ran P (2007): Biomass fuels are the probable risk factor for chronic obstructive pulmonary disease in rural South China. Thorax 62, 889-97

Lui KH, Dai WT, Chan CS, Tian L, Ning BF, Zhou Y, Song X, Wang B, Li J, Cao JJ (2017): Cancer risk from gaseous carbonyl compounds in indoor environment generated from household coal combustion in Xuanwei, China. Environmental Science & Pollution Research 24, 1-11

Ma L, Li Z, Tang Z, Sun F, Diao L, Li J, He Y, Dong B, Li Y (2017): Prevalence and socio-demographic characteristics of disability in older adults in China: Findings from China Comprehensive Geriatric Assessment Study. Archives of Gerontology and Geriatrics 73, 199-203

Mackenbach JP, Martikainen P, Looman CW, Dalstra JA, Kunst AE, Lahelma E (2005): The shape of the relationship between income and self-assessed health: an international study. International Journal of Epidemiology 34, 286-93

Madureira J, Paciência I, Cavaleirorufo J, De OFE (2016): Indoor pollutant exposure among children with and without asthma in Porto, Portugal, during the cold season. Environmental Science & Pollution Research 23, 20539-20552

Malla S, Timilsina GR (2014): Household Cooking Fuel Choice and Adoption of Improved Cookstoves in Developing Countries: A Review. Social Science Electronic Publishing

Mendes A, Papoila AL, Carreiro-Martins P, Bonassi S, Caires I, Palmeiro T, Aguiar L, Pereira C, Neves P, Mendes D (2016): The impact of indoor air quality and contaminants on respiratory health of older people living in long-term care residences in Porto. Age & Ageing 45(1), 136–142.

Mishra V (2003): Effect of indoor air pollution from biomass combustion on prevalence of asthma in the elderly. Environmental Health Perspectives 111, 71-8

National Energy Administration (2015): The task of solve the electricity-use problems of people without access to electricity was successfully completed http://www.nea.gov.cn/2015-12/24/c_134948340.htm

Peabody JW, Riddell TJ, Smith KR, Liu Y, Zhao Y, Gong J, Milet M, Sinton JE (2005): Indoor air pollution in rural China: cooking fuels, stoves, and health status. Archives of Environmental & Occupational Health 60, 86-95

Pope DP, Mishra V, Thompson L, Siddiqui AR, Rehfuess EA, Weber M, Bruce NG (2010): Risk of low birth weight and stillbirth associated with indoor air pollution from solid fuel use in developing countries. Epidemiologic Reviews 32, 70

Qu JS, Qin SS, Liu LN, Zeng JJ, Bian Y (2016): A hybrid study of multiple contributors to per capita household CO2 emissions (HCEs) in China. Environmental Science & Pollution Research 23, 6430-6442

Qu W, Yan Z, Qu G, Ikram M (2015): Household Solid Fuel Use and Cardiovascular Disease in Rural Areas in Shanxi, China. Iranian Journal of Public Health 44, 625-638

Siddiqui AR, Lee K, Bennett D, Yang X, Brown KH, Bhutta ZA, Gold EB (2009): Indoor carbon monoxide and PM2.5 concentrations by cooking fuels in Pakistan. Indoor Air 19, 75-82

Sirven N, Debrand T (2008): Social participation and healthy ageing: An international comparison using SHARE data. Social science & medicine 67, 2017-2026

Smith K, Samet J, Romieu I, Bruce N (2000): Indoor air pollution in developing countries and acute lower respiratory infections in children. *Thorax* 55, 518-32

Smith KR, Mehta S, Maeusezahl-Feuz M (2004): Indoor air pollution from household use of solid fuels. Comparative Quantification of Health Risks: Global and Regional Burden of Disease Attributable to Selected Major Risk Factors 2,1435-1493.

Stock JH, Watson MW (2002): Introduction to econometrics. Oxford University Press.

Suk WA, Ahanchian H, Asante KA, Carpenter DO, Diaz-Barriga F, Ha EH, Huo X, King M, Ruchirawat M, da Silva ER, Sly L, Sly PD, Stein RT, van den Berg M, Zar

H, Landrigan PJ (2016): Environmental Pollution: An Under-recognized Threat to Children's Health, Especially in Low- and Middle-Income Countries. Environmental Health Perspectives 124, A41-A45

Tang X, Liao H (2014): Energy poverty and solid fuels use in rural China: Analysis based on national population census. Energy for Sustainable Development 23, 122-129

Wang B, Liu YY, Li ZJ, Li ZW (2016): Association of indoor air pollution from coal combustion with influenza-like illness in housewives. Environmental Pollution 216, 646-652

Wang S, Ungvari GS, Forester BP, Chiu HF, Wu Y, Kou C, Fu Y, Qi Y, Liu Y, Tao Y (2017): Gender differences in general mental health, smoking, drinking and chronic diseases in older adults in Jilin province, China. Psychiatry Research 251, 58-62

Wei S, Shen G, Zhang Y, Xue M, Xie H, Lin P, Chen Y, Wang X, Tao S (2014): Field Measurement on the Emissions of PM, OC, EC and PAHs from Indoor Crop Straw Burning in rural China. Environmental Pollution 184, 18-24.

WHO (2002): The world health report 2002: Reducing Risks, Promoting Healthy Life. World Health Organization. http://www.who.int/whr/2002/en/

WHO (2016a): Household air pollution and health. World Health Organization. http://www.who.int/indoorair/en/

WHO (2016b): Multisectoral action for a life course approach to healthy ageing: Draft global strategy and plan of action on ageing and health. World Health Organization: Geneva, Switzerland

Wu H, Ouyang P (2017): Fall prevalence, time trend and its related risk factors among elderly people in China. Archives of Gerontology and Geriatrics. 73, 294-299.

Wu Y, Dang J (2013): China report of the development on aging cause. Social Sciences Acadamic Press: Beijing, China

Zhang S, Liu Z, Liu Y-L, Wang Y-L, Liu T, Cui X-B (2017): Prevalence of stroke and associated risk factors among middle-aged and older farmers in western China. Environmental Health and Preventive Medicine 22, 6. Doi: 10.1186/s12199-017-0621-z.