The Impact of Household Fuel Use for Cooking on Residents' Cognitive Abilities in China

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Abstract: This paper investigates the impacts of household use of solid fuels for cooking on cognitive ability in adults older than 16 years. We match the individual data from a nationally representative longitudinal survey of Chinese Family Panel Studies in 2010, 2014 and 2018, and outdoor air pollution in China by the exact time and geographic locations of cognitive ability tests. We use unbalanced panel fixed effect models to examine the impacts of household fuel use for cooking on cognitive ability, and panel instrumental variable method to address potential endogenous concerns associated with household use of solid fuel for cooking and cognitive ability. We find that household use of solid fuels for cooking significantly decreases mathematical cognitive ability rather than verbal cognitive ability. We also find that daily housework length and expenditures on culture, education, and recreation are two underlying mechanisms through which household use of solid fuels for cooking affects mathematical cognitive ability. Furthermore, we provide evidence that the negative effect of household use of solid fuels for cooking on mathematical cognitive ability becomes more pronounced among middle-aged and elderly people, for females, and for people who lived in southern China. Finally, exercise reduces the negative effects of household use of solid fuels for cooking on cognitive ability. These findings are new compared to the existing literature.

***Keywords*:** household fuel use for cooking, indoor air pollution, cognitive ability, China

1. Introduction

During recent years, a large body of literature has explored the effects of air pollution on cognitive ability (Lai et al., 2022; Zhang et al., 2018). The health risks associated with indoor air pollution have received increasing attention. Thus, a growing body of literature has begun to investigate the impact of indoor air pollution on cognitive ability (Krishnamoorthy et al., 2018; Künn et al., 2023; Liu et al., 2022; Qiu et al., 2019; Saenz et al.,2018). These studies show that indoor air pollution generated by household use of solid fuels for cooking or heating also has a negative impact on physical health and cognitive ability.

Our study finds that household use of solid fuels for cooking significantly decreases mathematical cognitive ability rather than verbal cognitive ability. We also find that daily housework length and expenditures on culture, education, and recreation are the underlying mechanisms through which household fuel use for cooking affects residents' cognitive abilities. Furthermore, we provide evidence that the negative effect of household use of solid fuels on mathematical cognitive ability becomes more pronounced for middle-aged and elderly people, for women, and for people who lived in southern China. In addition, exercise is beneficial in reducing the negative association between household use of solid fuels and residents' cognitive abilities. These findings are new compared to the existing literature.

Our study contributes to the existing literature. Firstly, we use a large nationally longitudinal survey in China that includes adults of all ages, rather than limiting to only the elderly people, thus leading to greater statistical power and more generalizable conclusions, which is a useful supplement to previous studies. Secondly, we use multi-year unbalanced panel data with year, individual and province fixed effects, family, and community characteristics, which reduces the bias and increases the precision of obtained results. Thirdly, we use the instrumental variable method to address reverse causality problem. Fourthly, we reveal two underlying mechanisms of the impact of household fuel use for cooking on residents' cognitive abilities and the possible heterogeneity.

2. Data and Methodology

2.1 Variables and Data

We use the data from China Family Panel Studies (CFPS), a national representative sample of people aged 16 years

and older. The CFPS, which began officially in 2010, is a biennial panel tracking survey that includes 162 districts in 25 provinces in China. The CFPS collects extensive information on demographic and socioeconomic characteristics, family and household characteristics, health status and cognitive abilities. The CFPS is particularly suitable for examining the impact of indoor air pollution generated by household use of solid fuels for cooking on cognitive ability. The main reasons lie in that the CFPS has rich information on cognitive ability and particularly on the type of fuel each household uses for cooking. Variable definitions are presented in Table 1.

Table 1. Variable definitions

Variable	Definition	Mean	S.D	Observations
Dependent variable				
Wordtest	The number of correct answers in verbal test	17.70	10.81	77347
Mathtest	The number of correct answers in mathematics test	9.92	6.54	77347
Key independent variable				
Fuel	1 for solid fuel for cooking, 0 otherwise	0.40	0.49	77347
Control variables				
Individual characteristics				
Age	Age of respondents	46.62	16.50	77347
Gender	1 if the gender of the respondents is female, 0 otherwise	0.51	0.50	77347
Education	0 is no schooling, 1 is primary school, 2 is junior high school, 3 is senior high school / vocational school, 4 is junior college, 5 is undergraduate college, 6 is graduate student	1.58	1.32	77347
Married	1 if married is, 0 otherwise	0.88	0.33	77347
Health change	If the worse is 1, no change is 2, and the improvement is 3	1.82	0.63	77347
Smoker	1 if smoking in the past month, 0 otherwise	0.30	0.46	77347
Drinker	1 If you drink three times a week in the past month, 0 otherwise	0.16	0.36	77347
Disease	1 if you have chronic diseases in the past 6 months, 0 otherwise	0.16	0.37	77347
Exec	Number of exercises in the past week	1.93	2.99	77304
Execfr	Exercise length in the past week(hour)	2.25	6.48	77275
Household characteristics				
lnperincome	Logarithm of household per-capita income	9.03	1.16	77347
Hukou	1 in rural area, 0 otherwise	0.52	0.50	77347
Household size	Family size	4.28	1.92	77347
Running water	1 If the domestic water is tap water, 0 otherwise	0.65	0.48	77347
Community characteristics				
PM2.5	Average annual PM2.5 concentration in the surveyed area	44.58	19.32	77347
Instrumental variables (IVs)				
IVfa	1 if family-level households engaged in agriculture, forestry, animal husbandry and fishery, 0 otherwise	0.56	0.50	77347
IVdt	1 is villa, 2 is apartment, 3 is bungalow, 4 is others	2.84	0.54	75964
Mechanism variables				
Housework	Daily housework length	1.96	1.84	77306
Ec	Logarithm of past-year household expenditures on culture, education, and recreation	5.25	4.01	77347

The dependent variables. In our study, cognitive test scores are used as the dependent variables, including verbal test scores (wordtest) and mathematical test scores (mathtest).

Key independent variable. Combustion of solid fuel (such as fuelwood, coal, straw and dung) is a dominant source of indoor air pollution. Here, the question from the investigation is: "what kind of fuel is the main fuel for cooking in your home?". Inspired by the literature (Saenz et al., 2018; WHO, 2018), we identify firewood and coal as solid fuels and canned gas, liquefied gas, natural gas, pipeline gas, solar energy, methane and electricity as clean fuels.

We use “whether family-level households are engaged in agriculture, forestry, animal husbandry and fishery” and “dwelling type” as two instrumental variables (IVs). We also use daily housework length and expenditures on culture,

education, and recreation as mechanism variables. Daily housework length is converted into daily average household length using standard weekday and rest day rules, defined as

$$housework\ daily\ length = \left[\frac{Workday\ housework\ time \times Rest\ day\ housework\ time \times 2}{7} \right].$$

The long-term effects of exercise on individual health are well demonstrated, and a general rather than domain-specific effect of exercise on cognition (Ludyga et al., 2020). The effect of exercise on the relationship between household use of solid fuels for cooking and residents' cognitive abilities is not known. Thus, we introduce the number of exercises in the past week and exercise length in the past week to explore the heterogeneity.

2.2 Econometric models

Our baseline econometric specification is defined as:

$$Score_{iht} = \beta_0 + \beta_1 fuel_{it} + \beta_2 PM_{2.5} + \lambda_i + \eta_t + \delta_h + \varepsilon_{iht} \quad (1)$$

where, $Score_{iht}$ is the cognition test scores of respondents i in district h in year t. $fuel_{it}$ is the type of cooking fuel of respondent i in year t. X_{it} is a set of the observable demographic correlates of the respondents. We also fix the effects of $PM2.5$ concentration in prefecture-level cities. λ denotes individual fixed effects. δ represents province fixed effects. η denotes year fixed effects. ε_{iht} is the error term. Standard errors (SE) are clustered at the individual level.

In the model estimations, the key identification challenge is the potential endogeneity resulting from reverse causality. Respondents' cognitive abilities may affect household fuel use for cooking. The traditional ordinary least squares method (OLS) may obtain bias estimations. Therefore, we use the panel instrumental variable method to address the endogeneity concerns and obtain reliable estimations. In the first stage, "whether family-level households are engaged in agriculture, forestry, animal husbandry and fishery" and "dwelling style" as two instrumental variables in stage I are used for estimation of the critical variable *Fuel*, which is substituted into stage II as the exogenous variable of cognitive scores.

To investigate the heterogeneity, we estimate the effects of household fuel use for cooking on residents' cognitive abilities across ages, gender, geographical location and exercise differences, respectively. In addition, We also use the interaction term to highlight the heterogeneity.

3. Results

3.1 Benchmark estimation results

Table 2 reports the estimations of household fuel use for cooking on residents' cognitive abilities (verbal test scores and math test scores). Indoor air pollution generated by household use of solid fuels for cooking has an adverse impact on mathematical cognitive ability, but has no significant effect on their verbal cognitive ability.

Table 2. Effects of indoor air pollution on cognitive test scores

Panel A: Word test					
Variable	(1)	(2)	(3)	(4)	(5)
	OLS	Model 1	Model 2	Model 3	Model 4
Fuel	-0.947***	0.108	0.121	0.098	0.094
	(0.063)	(0.128)	(0.129)	(0.128)	(0.128)
Individual control	YES	NO	YES	YES	YES
Family control	YES	NO	YES	YES	YES
Community control	YES	NO	NO	YES	YES
Observations	77,347	77,347	77,347	77,347	77,347
R^2	0.571	0.900	0.901	0.903	0.903
Individual fixed effect	NO	NO	YES	YES	YES
Year fixed effect	NO	NO	NO	YES	YES
Province fixed effect	NO	NO	NO	NO	YES
Panel B: Math test					
Fuel	-0.302***	-0.163**	-0.184***	-0.186***	-0.186***

	(0.030)	(0.070)	(0.069)	(0.069)	(0.069)
Individual control	YES	NO	YES	YES	YES
Family control	YES	NO	YES	YES	YES
Community control	YES	NO	NO	YES	YES
Observations	77,347	77,347	77,347	77,347	77,347
R^2	0.731	0.915	0.919	0.920	0.920
Individual fixed effect	NO	NO	YES	YES	YES
Year fixed effect	NO	NO	NO	YES	YES
Province fixed effect	NO	NO	NO	NO	YES

Notes: *, **, and *** are significant at the levels of 10%, 5%, 1%, respectively; Robust standard errors, clustered at the individual level, are presented in parentheses. Model 1 only adds the variable age.

Firstly, we focus on the verbal test scores. As shown in Panel A of Table 3, except for the OLS estimation, all of the coefficients for *Fuel* are not statistically significant, which indicates that there is no statistical relationship between household fuel use for cooking on residents' cognitive abilities after fixing individual, year and province effects. If individual, year and province fixed effects are not controlled for such as in the OLS model, it may lead to endogenous concerns, and individual differences, year and province changes play an important role in health outcomes.

Secondly, we conduct a considerable study of math test scores. As shown in Panel B of Table 3, using solid fuels for cooking has a negative impact on the math test score, with the coefficient estimates of -0.163, -0.184, -0.186, and -0.186, respectively. In other words, math test scores are 0.186 points lower for respondents who use solid fuels for cooking in households than respondents who use clean fuels.

3.2 Robustness tests

Firstly, to obtain a consistent estimation of household fuel use for cooking and residents' cognitive abilities relationship, we control for a series of variables, individual, year and province fixed effects. In our study, the major concern for endogeneity may arise from the reverse causality in household fuel use for cooking and cognitive abilities relationship. It may also be possible that low cognitive ability may use solid fuels. Thus, we adopt the instrumental variable and panel instrumental variable method to address the endogeneity concerns arising from reverse causality.

We use “whether family-level households are engaged in agriculture, forestry, animal husbandry and fishery” and “dwelling type” as household-specific characteristics, which create exogenous variations in fuel choice of the households and serve as IVs for our endogenous variables. Columns (1)-(3) of Table 3 reports the panel instrumental variable method estimations. The panel instrumental variable estimations show that there is a significantly negative relationship between household use of solid fuels and mathematical cognitive ability.

Secondly, we use the air quality index (AQI) to replace PM2.5 concentration for a robustness test. As shown in columns (4) and (5) of Table 3, the estimations are consistent with our benchmark estimations. The coefficient of *Mathtest* on *Fuel* is -0.295 and is statistically significant at the level of 5%, which suggests that the estimation is robust by using alternative measures of outdoor air pollution.

Thirdly, we adjust the prefecture-level PM2.5 concentration into province-level PM2.5 concentration as a robustness test. As shown in columns (6) and (7) of Table 3, the estimations are consistent with our benchmark estimation with a significant negative coefficient of *Fuel* (-0.187) on *Mathtest* at the significance level of 1%. However, the verbal test score is not statistically significant at the level of 10%.

Our benchmark estimation is robust to a wide variety of specification checks. Thus, we infer that household use of solid fuels for cooking has a significant negative effect on mathematical cognitive ability, but not on verbal cognitive ability.

Table 3. Robustness tests

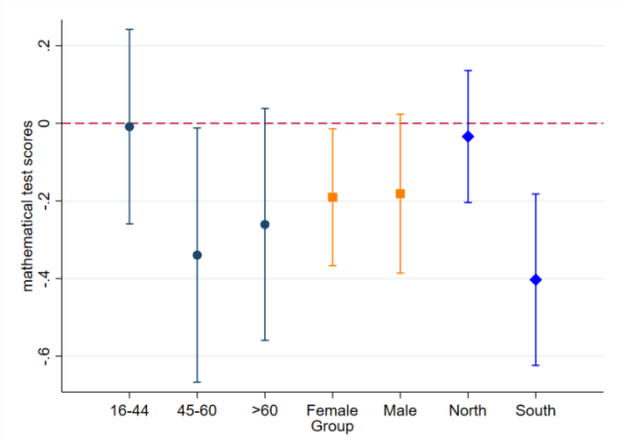
Variable	Wordtest		Mathtest	Wordtest	Mathtest	Wordtest	Mathtest
	First stage	Second stage					
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Fuel		0.154	-1.411*	-0.225	-0.295**	0.100	-0.187***
		(1.408)	(0.777)	(0.260)	(0.147)	(0.128)	(0.069)
IVfa	0.030***						
	(0.004)						

IVdt	0.036***						
	(0.005)						
Individual control	YES	YES	YES	YES	YES	YES	YES
Family control	YES	YES	YES	YES	YES	YES	YES
Community control	YES	YES	YES	YES	YES	YES	YES
Observations	57809	57809	57809	47,085	47,085	77,347	77,347
R^2		0.026	0.095	0.934	0.934	0.903	0.920
Individual fixed effect	YES	YES	YES	YES	YES	YES	YES
Year fixed effect	YES	YES	YES	YES	YES	YES	YES
Province fixed effect	YES	YES	YES	YES	YES	YES	YES
F-statistic	62.556						
Sargan statistic		0.594	1.283				
Chi-sq(1) P-value		0.44	0.26				

Notes: The community control in column (4) and (5) of Table 3 is AQI, and the community control in column (6) and (7) of Table 3 is province-$PM_{2.5}$. *, **, and *** are significant at the levels of 10%, 5%, 1%, respectively. Columns (2) and (3) with z-statistics in parentheses. Columns (4)-(7) with robust standard errors, clustered at the individual level, are presented in parentheses.

3.3 Heterogeneity analysis

Our research shows that household use of solid fuels for cooking has a negative effect on mathematical cognitive ability, which may have a heterogeneous effect across subgroups. To provide a more comprehensive analysis, we examine the effect of household use of solid fuels for cooking on mathematical cognitive ability across age, gender, and location differences. Figure 1 plots the estimated coefficients for each subsample with 95% confidence intervals.



Notes: Respondents' ages in the regression are those recorded during the respective survey periods.

Figure 1. Effects of household fuel use for cooking on mathematical test scores across Age, Gender and Location.

We first divide ages into three categories according to the World Health Organization (WHO) criteria, namely young group (16-44 years old), middle-aged group (45-60 years old), and elderly group (over 60 years old). The estimations in Table 4 show that household use of solid fuels for cooking has a significant negative association with the mathematical cognitive ability of middle-aged and elderly people, with the coefficients of -0.320 and -0.282, respectively, rather than that of young people.

We also examine the heterogeneous effect of household fuel use for cooking for male and female respondents, respectively. Because female is primarily responsible for preparing meals and doing housework, they are more likely to have prolonged exposure to indoor air pollution than male. Thus, it is expected to find that female respondents have incurred a greater impact. Columns (4) and (5) of Table 4 confirm this hypothesis and show that household use of solid fuels for cooking is associated with the lower mathematical cognitive ability of both male respondents and female respondents. The statistical significance of female respondents is higher than that of male respondents. The gender difference is statistically significant at the level of 5%. On average, female respondents in households that use solid fuels for cooking answer 0.191

fewer questions correctly (relative to household use of non-solid fuel), while male respondents in households that use solid fuels for cooking answer 0.181 fewer questions correctly.

Furthermore, we continue to examine the impact of heterogeneous across north and south regions, divided by the Qin Mountain-Huai River line of China. In north China, where outdoor air pollution is more severe, people in the north are more likely to suffer health problems from outdoor effects. Respondents who are in the south have lower scores, both for verbal test scores (16.86) and math test scores (9.67), than those in the north (18.41 and 10.14). Columns (6) and (7) in Table 4 respectively report the estimations using north and south samples, which are consistent with our expectations.

Table 4. Impacts of indoor air pollution on mathematical cognition ability across groups

Variable	Mathtest						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	16-44	45-60	>60	Male	Female	North	South
Fuel	-0.009	-0.320**	-0.282*	-0.181*	-0.191**	-0.034	-0.403***
	(0.128)	(0.157)	(0.162)	(0.090)	(0.104)	(0.087)	(0.113)
Individual control	YES	YES	YES	YES	YES	YES	YES
Family control	YES	YES	YES	YES	YES	YES	YES
Community control	YES	YES	YES	YES	YES	YES	YES
Observations	34,452	25,713	17,182	38,107	39,240	41,709	35,638
R^2	0.947	0.912	0.903	0.900	0.933	0.913	0.927
Individual fixed effect	YES	YES	YES	YES	YES	YES	YES
Year fixed effect	YES	YES	YES	YES	YES	YES	YES
province fixed effect	YES	YES	YES	YES	YES	YES	YES

Notes: *, **, and *** are significant at the levels of 10%, 5%, 1%, respectively. Robust standard errors, clustered at the individual level, are presented in parentheses.

To more clearly reported the heterogeneity, we adopt the interaction term. The estimation results are reported in columns (1) and (2) of Table 5, and the interaction term of household cooking fuel use and gender has a significant negative effect on the math test scores. This result indicates that females suffer from a greater degree of cognitive decline in household use of solid fuels for cooking than males. The interaction term between household cooking fuel use and the North-South region dummy variable has a significant positive effect on the math test scores in terms of the difference between North and South. The results suggest that the North suffers a weaker decline in household use of solid fuel for cooking than the South.

Exercise has been shown to be effective in improving health. Here, we introduce the number of exercises and exercise length in the past week to illustrate the effect of exercise on household fuel use for cooking and math test scores. Table 5 reports the estimation results. In Column (3), the interaction term between Exec*Fuel is positive and significant at the level of 1%, indicating that the number of exercises reduces the cognitive risk associated with household use of solid fuels for cooking. In column (4), the interaction term between Execfr*Fuel is positive and significant at the level of 1%, implying that longer exercise duration effectively reduces the risk of cognitive decline. Therefore, our results demonstrate the effectiveness of exercise on cognitive improvement (Ludyga et al., 2020).

Table 5. Heterogeneity analysis

Variables	(1)	(2)	(3)	(4)
	Female	North	Mathtest	Mathtest
Fuel	-0.008	-0.478***	-0.301***	-0.244***
	(0.101)	(0.106)	(0.074)	(0.070)
Gender	0.034			
	(0.887)			
*Gender*Fuel*	-0.350***			
	(0.130)			
Northsouthcity		-3.485		
		(2.120)		

*Northsouthcity*Fuel*		0.489***		
		(0.133)		
Exec			-0.006	
			(0.011)	
*Exec*Fuel*			0.069***	
			(0.017)	
Execfr				-0.010**
				(0.005)
*Execfr*Fuel*				0.029***
				(0.007)
Individual control	YES	YES	YES	YES
Family control	YES	YES	YES	YES
Community control	YES	YES	YES	YES
Observations	77,347	77,347	77,304	77,275
R^2	0.920	0.920	0.920	0.920
Individual fixed effect	YES	YES	YES	YES
Year fixed effect	YES	YES	YES	YES
Province fixed effect	YES	YES	YES	YES

Notes: *, **, and *** are significant at the levels of 10%, 5%, 1%, respectively. Robust standard errors, clustered at the individual level, are presented in parentheses.

3.4 The mechanism analysis between indoor air pollution and mathematical test scores

In this section, we continue to study how household use of solid fuels for cooking affects mathematical cognitive ability. We choose daily housework length for the mechanism analysis. Clean fuels burn more efficiently, leading to less time spent on cooking. However, a shorter duration of cooking is associated with lower pollution exposure, thereby supporting that the reduction in pollution exposures is the main channel. Another possibility is that using clean fuel also saves time for fuel refilling, cleaning up the stove, or cleaning up the kitchen (Imelda, 2020).

Column (2) of Table 6 supports that household use of solid fuels for cooking is positively correlated with daily housework length, while respondents in households that use non-clean fuel for cooking spend more time on housework activities. The comparison of the mean values in Table 6 also shows that the respondents in households that use solid fuel for cooking put in a longer time for housework activities. Columns (2) and (3) of Table 6 show that the relationship between household use of solid fuel for cooking and the cognitive ability of the respondents when the mechanism is not included and included, respectively. The estimated coefficients of *Fuel* and *Housework* are -0.183 and -0.010, respectively.

The negative effect of household fuel use for cooking on cognitive ability may be also driven by behavioral change. Respondents may become more impatient when exposed to more polluted indoor air. Therefore, it is possible that the observed negative effect on cognitive ability is due to behavioral change rather than impaired cognitive. To check this possibility, we examine the impact of exposure to indoor air pollution and impatience during the interview. Column (4) of Table 6 displays the estimations, which shows that there is no significant association between household fuel use for cooking and respondents' impatience, ruling out the behavioral channel.

It is well known that household use of solid fuels for cooking increases physical health risks, and therefore, people may spend more on health care, etc., and less on culture, education, and recreation. As the column (5) and (6) of Table 6 shows, household use of solid fuels for cooking significantly reduces household spending on culture, education, and recreation in the past year, and since education has been shown to be effective in raising cognitive ability (Kremen et al., 2019), it is reasonable to assume that the reduction in culture, education, and recreation could be one of the channels.

Table 6. Mechanism analysis between indoor air pollution and mathematical test scores

Variables	(1)	(2)	(3)	(4)	(5)	(6)
	Mathtest	Housework	Mathtest	Impatience	Ec	Mathtest
Fuel	-0.184***	0.077*	-0.183***	-0.024	-0.135*	-0.183***
	(0.069)	(0.040)	(0.069)	(0.080)	(0.079)	(0.069)
Housework			-0.010			
			(0.014)			
Ec						0.022***
						(0.007)
Individual control	YES	YES	YES	YES	YES	YES
Family control	YES	YES	YES	YES	YES	YES
Community control	YES	YES	YES	YES	YES	YES
Observations	77,306	77,306	77,306	47,082	77,347	77,347
R^2	0.920	0.687	0.920	0.718	0.721	0.920
Individual fixed effect	YES	YES	YES	YES	YES	YES
Year fixed effect	YES	YES	YES	YES	YES	YES
Province fixed effect	YES	YES	YES	YES	YES	YES

Notes: *, **, and *** are significant at the levels of 10%, 5%, 1%, respectively. Robust standard errors, clustered at the individual level, are presented in parentheses.

4. Discussion and policy implications

Concerns have been raised worldwide regarding the impact of air pollution on physical health. Compared with outdoor air pollution, evidence on the impact of household fuel use for cooking on cognitive ability is still limited in the literature. Our study seeks to strengthen our understanding of the impact of household use of solid fuels for cooking on cognitive ability. We use years of CFPS data, panel fixed effect models, and sociodemographic variables, which are likely important factors influencing household fuel choice and health outcomes. By controlling for individual, province, and year effects, our study suggests that household use of solid fuels for cooking has an adverse effect on mathematical cognitive ability. In particular, our finding shows that daily housework length and expenditures on culture, education, and recreation are underlying mechanisms through which household use of solid fuels for cooking affects cognitive ability. Taken together, these results highlight a need for households to switch to cleaner fuels.

Air pollution imposes a substantial health and economic burden. China continues to experience a rise in the prevalence of cognitive impairment. Our results have important policy implications. To improve public health, China has implemented a series of policies during recent years, such as improved cooking stoves, fuel subsidies, infrastructure development, which are effective ways to promote cooking fuel transformation (Cesur et al., 2018; Imelda, 2020). In the process of the poverty alleviation plan, the Chinese government can popularize relevant clean and healthy information and provide greater subsidies for household fuel. In addition to the poor households mentioned above, the main problem is the lack of public awareness of indoor air pollution and the benefits of using improved stoves and cleaner fuels. Therefore, relevant health education and publicity are still necessary. Furthermore, the popularization of higher education is particularly important. For policymakers, our conclusions should be regarded as further evidence of restrictions on household use of solid fuels. For individuals, it is important to fully understand the relevant information on indoor air pollution. The possibility of ventilation should be expanded when clean fuels are not effectively available.

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