Household Energy Choice for Cooking: Do Rural Income Growth and Ethnic Difference Play a Role?

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Selected Paper prepared for presentation at the 2021 International Association of Agricultural Economics (IAAE) Triennial (Virtual) Conference, August 17-31, 2021

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Abstract

This paper investigates the associations between rural income growth, ethnic differences, and household cooking fuel choice, using the 2016 China Labor-force Dynamics Survey Data. We consider the presence of fuel-stacking behavior (using multiple fuels) amongst survey households and classify cooking fuels into clean fuels, non-clean fuels, and mixed fuels. Data collected from 6,461 rural households are estimated using a multinomial logit model. Findings suggest that relative to households at the lowest income quintile 1, those at the income quintiles 2-5 are more likely to use clean fuels rather than non-clean fuels for cooking, and the magnitudes of the effects increase across the income quintiles. Compared with the majority Han Chinese households, ethnic minority households are more likely to use mixed fuels rather than clean fuels for cooking. Only those ethnic minority households at the highest income level (quintile 5) appear to be more likely to use clean cooking fuels.

Keywords: Income growth; Ethnic differences; Cooking fuel choice; MNL model; China

JEL codes: P25, R11, Q42

1. Introduction

Cooking is an indispensable part of human life. However, the widespread cooking practices with non-clean fuels, such as firewood, straw, dung, and coal, negatively impact the environment and human health. Non-clean cooking fuel use results in, for example, climate change, deforestation, biodiversity loss, indoor air pollution, low birth weight, coughing and breathing difficulties, acute respiratory infection, and chronic obstructive pulmonary disease (Alem et al. 2016; Chafe et al. 2014; Niu et al. 2014; Seow et al. 2016; Wang et al. 2017; WHO 2018; Xu et al. 2018; Yu et al. 2020; Yun et al. 2020). It is reported that around 52% of the world's population rely on non-clean fuels for cooking and heating, and indoor air pollution generated by non-clean fuel use causes the deaths of estimated 1.6 million people annually (WHO 2020). James et al. (2020) estimated the impact of household cooking fuel use on rural women's health outcomes in India. They found that women, who are exposed to biomass fuel, are significantly associated with their self-reported ophthalmic conditions, respiratory symptoms, cardiovascular diseases, dermatological symptoms, and history of adverse obstetrical outcomes.

In comparison, the use of clean fuels (e.g., liquefied petroleum gas (LPG), natural gas, electricity, or biogas) for cooking brings in positive externalities, such as improving energy users' health performance, promoting gender equality, and enhancing sustainable management of natural resources (Capuno et al. 2018; Carter et al. 2020; Gould and Urpelainen 2018; Liu et al. 2020; Liu et al. 2020; Rahut et al. 2016b; Ravindra et al. 2019; Rosenthal et al. 2018; Zahno et al. 2020). Capuno et al. (2018) found that clean cooking fuels' usage helps lower the incidence of severe coughing with difficulty in breathing in young children by 2.4 percentage points in the Philippines. Yu et al. (2020) found that compared with persistent non-clean cooking fuel users, persistent clean fuel users have significantly lower risks of all-cause mortality, cardiovascular mortality, and respiratory mortality in China. "Ensuring access to affordable, reliable, sustainable and modern energy for all" is also listed as one of the 17 Sustainable Development Goals by the United Nations General Assembly. Therefore, it is essential to promote the cooking energy transition from non-clean fuels to clean fuels from a sustainable development perspective.

A growing number of studies have investigated the patterns and determinants of cooking fuel choices (Alem et al. 2016; Chen et al. 2016; Heltberg 2004; Hou et al. 2017; Makonese et al. 2018; Paudel et al. 2018; Rahut et al. 2017; Twumasi et al. 2020; Yasmin and Grundmann 2020). Among various socioeconomic factors affecting household cooking fuel choice, income plays a vital role. The energy ladder theory states that households tend to shift energy consumption patterns from non-clean fuels to clean fuels with increasing household income. However, previous studies have mainly analyzed the mean-based income effects on household cooking fuel choices (Jaime et al. 2020; Liao et al. 2019; Ma et al. 2019; Wang and Jiang 2017; Yang et al. 2020), with little attention being paid to the potential heterogeneous income effects. From 2013 to 2019, rural households' disposable income in China has increased by around 70%, moving from 9.43 thousand yuan/capita to 16.02 thousand yuan/capita.[1] Promoting cooking energy transition can also help Chinese government strengthen its climate target by achieving peak carbon emissions before 2030 and carbon neutrality before 2060 (Normile 2020). Therefore, a better understanding of the nexus between income and cooking fuel choices can provide useful evidence for designing energy transition policies for a country like China, whose rural income has experienced fast growth in recent years and energy transition has been encouraged by the government.

China is a multi-ethnic country, which comprises 55 ethnic minority groups and the Han Chinese majority (Maurer-Fazio and Hasmath 2015; Yang et al. 2020). The ethnic minority groups should be given special attention when making efforts to achieve the energy consumption sustainability goal for all. Available statistical data show that the ethnic minority population increased by 10.26% from 2000 to 2015, while the Han Chinese population only increased by 8.34% during the same period (NBSC 2015).[2] There exist notable differences in income and cooking energy use between ethnic minority households and the majority Han Chinese households. In general, ethnic minority households are associated with relatively lower income and slower income growth than their Han counterparts (Gustafsson and Shi 2003a; Lin Liu et al. 2019). Relative to ethnic minority households, Han Chinese households are less likely to use firewood but are more likely to use coal and electricity for cooking (Liao et al. 2019; Yang et al. 2020). Therefore, understanding income growth and cooking fuel choice among ethnic minority households can help design targeted rural energy transition policy for all.

Regarding the identification and measurements of cooking fuels, the existing literature can be divided into three strands. The first strand measures cooking fuel use as a dichotomous

[1] During the same period, the disposable income of urban households increases by 60%.

[2] In 2015, the populations of ethnic minority people and the majority Han Chinese people reached 0.01 billion (8.54% of the total population) and 1.26 billion (91.46% of the total) in 2015.

decision, which indicates whether a household has used clean fuels or non-clean fuels for cooking (e.g., Heltberg, 2004; Liu et al., 2020; Liu et al., 2020; Twumasi et al., 2020). The second strand captures the cooking fuel consumption quantity or expenditure (e.g., Chen et al., 2006; Mottaleb et al., 2017; Ngui et al., 2011; Niu et al., 2014; Twumasi et al., 2020; Wang and Feng, 2001). The third strand of literature considers different fuel types and assumes that these fuel choices are mutually exclusive (e.g., Paudel et al., 2018; Rahut et al., 2017, 2016a). In other words, households select one of them for cooking. For example, Paudel et al. (2018) investigated the factors affecting Afghani households' decisions to choose three types of cooking energies: LPG, wood, and straw. However, the findings reported in the three strands of the literature are hard to be generalized because, in reality, people may use two or more fuels for cooking rather than relying on a single one. Besides, some households may combine clean fuels with non-clean fuels (i.e., use mixed fuels) in their cooking practices as this strategy provides users with a sense of energy security.

This study extends the previous studies by investigating associations between rural income growth, ethnic differences, and household cooking fuel choice. A better understanding of the factors that motivate and hinder cooking fuel choice would help the governments in China and other countries design instruments that promote the rural energy transition and sustainable energy development. We focus on rural households rather than urban households because the former are more vulnerable to energy poverty due to lower income levels, underdeveloped infrastructures for energy transmission, and lower cognition of health and environmental effects associated with energy use (Alem et al. 2016; Hou et al. 2018; Khandker et al. 2012; Rahut et al. 2016b).[3] It is also relatively more common for rural households to use non-clean cooking fuels, especially in developing and transition countries (He et al. 2018; James et al. 2020b; Paudel et al. 2018). Thus, reducing energy poverty and promoting energy transition should pay special attention to rural households. We estimate the 2016 China Labor-force Dynamics Survey Data of 6,461 rural households, using a multinomial logit model.

We attempt to contribute to the literature from three significant aspects. First, we consider fuel-stacking behavior (using multiple fuels) and classify cooking types into clean fuels only, non-clean fuels only, and mixed fuels. The category "clean fuels" refers to cooking energy

[3] Although we focus on rural households, in Section 4.3, we also present and briefly discuss the results estimated for the urban household samples to enrich our understanding regarding the relationship between income growth, ethic differences, and household cooking fuel choice.

sources such as liquid gas, electricity, natural gas, methane, and solar energy. Each household chooses one or more clean fuels for cooking. The category "non-clean fuels" refers to firewood and coal. Households choose either of them or combine them for cooking. The term "mixed fuels" refers to a combination of at least one clean fuel and one non-clean fuel. For example, a household may use both an induction cooker and a wood/coal stove for daily cooking practices. We are aware of only one study in the published literature (Alem et al. 2016) that considered the fuel-stacking behavior by classifying cooking fuels into clean fuels (kerosene and electricity), biomass (firewood and charcoal), and mixed. However, this study focuses on the household cooking fuel choice of urban households in Ethiopia, without considering rural households. No studies have investigated the nexus between income and the fuel-stacking behavior of Chinese households. Addressing this gap is significant as energy transition from non-clean fuels to clean fuels needs to get through the "route" of mixed fuels, and the usage of mixed fuels for cooking is quite common in China.

Second, we measure household income in a quintile way to test whether richer and poorer households make homogeneous or heterogenous decisions when choosing cooking fuels and how income affects rural households' decisions of choosing mixed fuels. Third, we go further and examine how ethnic differences and income growth amongst ethnic minority households affect cooking fuel choice. By doing this, we include both minority variable and multiplicative interaction terms between income quintile variables and minority variable in our model. With the notable exceptions of Liao et al. (2019) and Yang et al. (2020), ethnic minority households' energy consumption has been overlooked in the literature. Liao et al. (2019) found that ethnic minority households are less likely to use coal, gas, and electricity for cooking than firewood. However, this study did not consider the fuel stacking behavior of households. Yang et al. (2020) only analyzed fuelwood consumption differences between majority Han Chinese households and ethnic minority households, without considering household consumption of clean fuels and mixed fuels.

The rest of this study is structured as follows. Section 2 introduces the theoretical framework and empirical specification. Section 3 presents data and descriptive statistics. Section 4 demonstrates and discusses the empirical results, while the final section concludes and proposes policy implications.

2. Theoretical framework and empirical specification

2.1 Theoretical framework

The theoretical framework employed in this study is based on the additive random utility model. The model has been widely applied in previous studies (e.g., Alem et al., 2016; Mensah and Adu, 2015; Paudel et al., 2018). For analytical settings, we assume that a household i chooses cooking fuel, k, from a bundle of available options, ψ, to maximize utility. i.e., $k \in \psi = \{1, 2, \dots, j\}$. These fuel options are mutually exclusive, so a household can only choose one for cooking practices. Let U_{ik} be the expected utility obtained from choosing cooking fuel k, and U_{im} be the expected utility obtained from choosing another cooking fuel m. Then, observing that household i chooses cooking fuel k rather than cooking fuel m implies that:

$$U_{ik} > U_{im}, \forall k \neq m \text{ and } k, m \in \psi \tag{1}$$

where k and m represent two different types of cooking fuels. We assume that U_{ik} is influenced by a set of observed factors (e.g., age, gender, education, family size, and asset ownership) and unobserved factors (e.g., individual motivations and intrinsic household preferences). Then, the U_{ik} can be assumed as a function of an observed component, V_{ik}, and an unobserved component, θ_{ik}. We further assume that the observed component V_{ik} is determined by a set of observed factors X_{ik} and an unknown parameter α_k, such that $V_{ik} = \alpha_k X_{ik}$. Therefore, we can obtain the following utility function:

$$U_{ik} = V_{ik} + \theta_{ik} = \alpha_k X_{ik} + \theta_{ik} \tag{2}$$

The probability of choosing cooking fuel k over other alternative m can be expressed as:

$$Pr_{ik} = \Pr(U_{ik} > U_{im}) = \Pr(U_{ik} - U_{im} > 0) = \Pr(V_{ik} - V_{im} > \theta_{im} - \theta_{ik}) \tag{3}$$

As discussed earlier, we consider three types of cooking fuels in this study, i.e., $k \in \psi = \{1, 2, 3\}$, including clean fuels only (k=1), non-clean fuels only (k=2), and mixed fuels (k=3). Then, without loss of generality, the probability of a household choosing clean fuels for cooking, Pr_{i1}, can be expressed as follows:

$$\begin{aligned} Pr_{i1} = \Pr(U_{i1} > U_{i2} \text{ and } U_{i1} > U_{i3}) = \Pr(V_{i1} - V_{i2} > \theta_{i2} - \theta_{i1} \text{ and } V_{i1} - V_{i3} \\ > \theta_{i3} - \theta_{i1}) \\ = \Pr(\hat{V}_{i,12} > \hat{\theta}_{i,21} \text{ and } \hat{V}_{i,13} > \hat{\theta}_{i,31}) \end{aligned} \tag{4}$$

where $\hat{V}_{i,12} = V_{i1} - V_{i2}$; $\hat{V}_{i,13} = V_{i1} - V_{i3}$; $\hat{\theta}_{i,21} = \theta_{i2} - \theta_{i1}$ and $\hat{\theta}_{i,31} = \theta_{i3} - \theta_{i1}$. Equation (4) indicates that a household will choose clean fuels instead of other alternatives (non-clean fuels or mixed fuels) for cooking practices if and only if the utility received from using clean fuels is larger than the utility obtained from using any other fuel options. Assuming that the joint density function of θ_{ik} is expressed as $g(\theta_{ik}) = g(\theta_{i1}, \theta_{i2}, \theta_{i3})$, then the cumulative probability function of choosing clean fuels (k=1) for cooking rather than other alternatives can be expressed as follows:

$$Pr_{i1} = \int_{-\infty}^{\hat{V}_{i,12}} \int_{-\infty}^{\hat{V}_{i,13}} g_1(\hat{\theta}_{i,21}, \hat{\theta}_{i,31}) d\hat{\theta}_{i,21} d\hat{\theta}_{i,31} \tag{5}$$

2.2 Empirical specification

Given that households are assumed to choose cooking fuels from three mutually exclusive options, we employ a multinomial logit (MNL) model to estimate the determinants of cooking fuel choices. Regarding the determinants, we focus on rural income growth and ethnic differences (i.e., key independent variables) while controlling for other individual and household level characteristics (i.e., control variables). The MNL model has been widely applied in the literature when the dependent variable has unordered multinomial choices (Liao et al. 2019; Mensah and Adu 2015; Paudel et al. 2018; Rahut et al. 2016b, 2017).

We assume that the probability of a household choosing a particular type of cooking fuel k is a function of a set of observed factors X_{ik} that is composed of key independent variables I_{ik} and control variables Z_{ik}. Then, the probability function of choosing cooking fuel k can be specified as follows:

$$Pr_{ik} = \alpha_{ik} I_{ik} + \beta_{ik} Z_{ik} + \upsilon_i \tag{6}$$

where Pr_{ik} refers to the probability of choosing cooking fuel option $k=\{1, 2, 3\}$; $I_{ik} + Z_{ik} = X_{ik}$; α_{ik} and β_{ik} are unknown parameters; υ_i is an error term, capturing the unobserved factors that affect the dependent variable.

To facilitate the discussions, the key independent variable (I_{ik}) in Equation (6) is further assumed to be a composition of household income variable, minority variable, and interaction terms between income and minority. We measure household income at quintile levels to better explore whether income affects household cooking fuel choices homogeneously or heterogeneously. Consistent with Yang et al. (2020), the minority variable is measured as a dichotomous variable, which is given a value of one if a household belongs to an ethnic minority group and zero otherwise.[4] Furthermore, we include a set of multiplicative interaction terms for income quintile variables and minority variables to investigate how income growth amongst rural ethnic minority households affects their cooking fuel choices. Regarding the control variables (Z_{ik}), we select them by drawing upon the existing literature

[4] In this study, we focus on ethimic minority households in general rather than a specific ethnic minority group for the sake of simplicity. Also, because China has 55 ethnic minority groups (e.g., Mongol, Manchu, Hui) and only 14% of households in our samples are ethnic minorities, it is not possible to focus on a specific ethnic minority group due to relatively small sample size.

on household cooking fuel choice (e.g., Amoah, 2019; Jaime et al., 2020; Liao et al., 2019; Liu et al., 2020; Paudel et al., 2018; Rahut et al., 2016a; Troncoso et al., 2019; Twumasi et al., 2020; Yasmin and Grundmann, 2020). Specifically, we include the variables representing age, gender and education of the respodents, family size, dependency ratio, pollution perception, car ownership, distance to country, and location dummies in this study.

Given the above discussions, we expand Equation (6) as follows:

$$Pr_{ik} = \sum_{h=1}^{h=4} \delta_{ikh} Income_{ikh} + \lambda_{ik} Ethnic_{ik} + \sum_{h=1}^{h=4} \varpi_{ikh} (Income_{ikh} \times Ethnic_{ik}) + \sum_{r=1}^{r=10} \phi_{ijr} Z_{ijr} + \mu_{ij} \quad (7)$$

where Pr_{ik} is defined earlier; $Income_{ikh}$ refers to a vector of household income quintile variables (h=4); $Ethnic_{ik}$ refers to the ethnic minority status of rural households; $Income_{ikh} \times Ethnic_{ik}$ refers to a vector of multiplicative interaction terms (h=4); Z_{ijr} refers to a vector of control variables (r=10). δ_{ikh}, λ_{ik}, ϖ_{ikh} and ϕ_{ijr} are parameters that will be estimated in the MNL model. μ_{ij} is a random error term.

3. Data and descriptive statistics

3.1 Data

The data collected in this study were obtained from the 2016 China Labor-force Dynamics Survey. The collected information targets for 2015. The Center for Social Science Survey at Sun-Yat-sen University (Guangzhou, China) managed the data collection, using a multistage cluster, stratified, probability proportional to size (PPS) sampling strategy. They collected data from urban and rural areas in 29 mainland provinces and municipalities (excluding Tibet and Hainan) so that the dataset is nationally representative. The dataset contains detailed information on the types of fuels used for cooking practices, demographic factors (e.g., age, gender, education, family size, and dependency ratio), socioeconomic factors (e.g., incomes and asset ownership), and geographic locations. Because this study focuses on examining the determinants of cooking fuel choices of rural households, we purposively extract the rural household samples in data cleaning while saving the urban household samples in a separate file for additional analysis. Then, we further deleted the rural samples with missing information. The final samples used for our empirical analysis include 6,461 rural households. Among them, 2,618 households only used clean fuels (i.e., liquid gas, electricity, natural gas, methane, and solar energy), 1,542 only used non-clean fuels (i.e., firewood or coal), and the rest 2,301 households mixed fuels for cooking.

3.2 Descriptive statistics

Table 1 presents the definitions and descriptive statistics of the selected variables. It shows that 41% of the surveyed households only used clean fuels for cooking. This is similar to the observation of Yu et al. (2020), who showed that 44% of respondents were persistent clean fuel users in China. The households using non-clean fuels and mixed fuels represent 24% and 36% in our sample, respectively. Table A1 in the Appendix demonstrates the details regarding each category of cooking fuels. It shows that clean fuels used by rural households include liquid gas, electricity, natural gas, methane, and solar energy. Among clean fuel users, most of them (46.72%) have used two fuels for cooking. This is followed by households using only liquid gas or electricity for cooking, which account for 24.33% and 23.80%, respectively. Firewood and coal are two major non-clean fuels used by rural households for cooking, and firewood dominates the role. Only 8.5% of non-clean fuel users combined firewood with coal for cooking. More than half of mixed fuel users (57.67%) used one clean fuel and one non-clean fuel for cooking.

Table 1 Variable definitions and summary statistics

Variables	Definition	Mean (S.D.)
Clean fuels	1 if household uses one or more clean fuels from available options (liquid gas, electricity, natural gas, methane, and solar energy) for cooking; 0 otherwise	0.41 (0.49)
Non-clean fuels	1 if household uses one or more non-clean fuels (firewood and coal for cooking; 0 otherwise	0.24 (0.43)
Mixed fuels	1 if household uses one or more clean fuels and one or more non-clean fuels for cooking; 0 otherwise	0.36 (0.48)
Income	Total household income (1,000 yuan/capita) [a]	9.94 (12.75)
Minority	1 if ethnic minority household (e.g., Mongol, Manchu, and Hui); 0 otherwise (Han Chinese household)	0.14 (0.35)
Age	Age of household head (HH) in years	53.33 (11.47)
Gender	1 if HH is male; 0 otherwise	0.91 (0.28)
Education	Education level of HH [b]	2.61 (1.16)
Family size	Number of family members in persons	4.65 (2.06)
Dependency ratio	Ratio of the number of people aged 0–14 years and those aged 65 years and over to the number of people aged 15–64 years	0.42 (0.50)
Pollution perception	HH’s perception of local air pollution seriousness level (1=not serious at all; 2=not serious; 3=serious; 4=very serious)	1.71 (0.81)
Car ownership	1 household owns one or more cars; 0 otherwise	0.16 (0.37)
Distance	Distance to the county (km)	26.32 (22.98)
Eastern	1 if household locates in the Eastern region; 0 otherwise	0.42 (0.49)
Central	1 if household locates in the Central region; 0 otherwise	0.27 (0.45)
Western	1 if household locates in the Western region; 0 otherwise	0.31 (0.46)
Observations		6,461

Note: [a] Yuan is Chinese currency (1USD = 6.64 yuan in 2016). [b] 1= illiterate; 2=primary school; 3=middle school; 4=high school; 5= vocational high school; 6=technical school; 7= technical secondary school; 8=junior college; 9=bachelor; 10=postgraduate.

On average, surveyed rural households earned 9,940 yuan/capita, which is quite similar to the rural disposable income at the national level in 2015 (10,489 yuan/capita) (CRSY 2019). 14% of surveyed households belong to ethnic minority groups. The mean age of household heads was 53 years old, and most of them (91%) were male. Averagely, there were around five members in the surveyed households. The mean dependency ratio was 0.42. The respondents generally perceived that local air pollution is not serious. Only 16% of surveyed households owned cars. In our samples, rural households located in Eastern, Central, and Western China account for 42%, 27%, and 31%, respectively.

As we are interested in understanding how income quintiles rather than general income affect household cooking fuel choice, in Figure 1, we demonstrate household income per capita for ethnic minority and Han Chinese households from income quintiles 1 to 5 for an apriori income distributions between the two groups of households. It shows that ethnic minority households have lower incomes than the Han Chinese households at all quintiles. Specifically, the income differences increase from 480 yuan/capita at quintile 1 to 2,860 yuan at quintile 3, and finally to 6,120 yuan/capita at quintile 5.

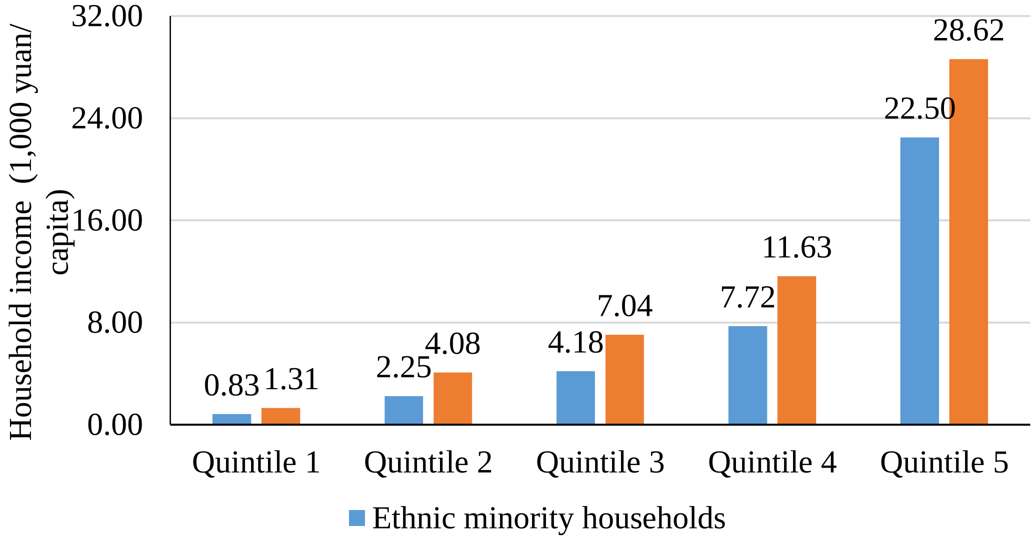

Figure 1 Household income per capita for ethnic minority and Han Chinese households at income quintiles

Figure 2 presents the household income per capita for ethnic minority and Han Chinese households by cooking fuel choices. The incomes of ethnic minority households are consistently lower than those of Han Chinese households in each cooking fuel category, which is in line with the findings in Figure 1. Compared with households that use non-clean or mixed fuels, those using clean fuels tend to have a higher income level. Households using non-clean fuels, no matter belong to an ethnic minority or Han Chinese household, have the lowest income among the three categories. Generally, the notable differences illustrated in Figures 1 and 2 suggest that cooking fuel choices may be affected heterogeneously by household income level and ethnic differences.

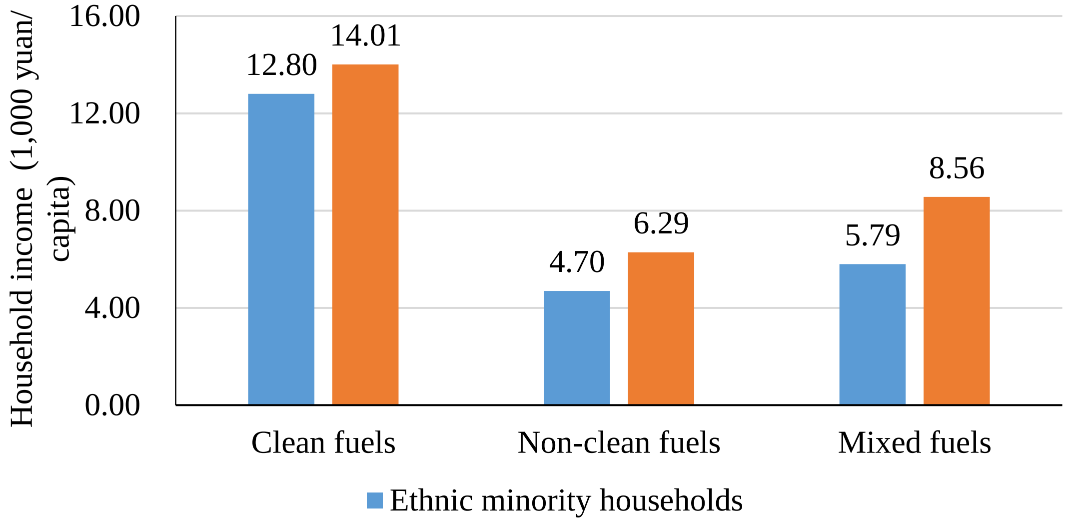

Figure 2 Household income per capita for ethnic minority and Han Chinese households by cooking fuel choices

Table 2 shows the mean differences of the variables by cooking fuel choices. We present the *F*-value and its corresponding statistical significances that indicate whether the means of the selected variables among the three cooking fuel choices are the same in the last column of Table 2. The statistical information demonstrates that almost all the selected variables (except for gender) show significant differences among the three groups. For example, compared with households using non-clean fuels and mixed fuels, those who use clean fuels have a higher income, and they tend to be younger, more educated, and more likely to own cars. It also reveals that households' cooking fuel choices are significantly different among ethnic minority households. The proportion of ethnic minority households using mixed fuels is higher than that of those using clean and non-clean fuels. Clean fuel users are associated with the lowest dependency ratio. Households living in eastern China are more likely to use clean fuels, while those residing in central and western China are more likely to use non-clean fuels. In general, the findings in Table 2 reveal that household cooking fuel choice is affected by various factors such as income, ethnic differences, and individual and household-level characteristics. In the next section, we provide empirical insights.

Table 2 Mean differences of the selected variables by cooking fuel choices

Variables	Clean fuels	Non-clean fuels	Mixed fuels	*F*-statistics
Income	13.89	5.98	8.09	240.76***
Minority	0.10	0.17	0.19	45.52***
Age	51.13	54.31	55.18	86.30***
Gender	0.91	0.92	0.91	0.59
Education	2.85	2.34	2.50	113.13***
Family size	4.56	4.46	4.89	24.77***
Dependency ratio	0.37	0.43	0.45	16.02***
Pollution perception	1.90	1.49	1.64	141.78***
Car ownership	0.26	0.08	0.11	159.74***
Distance	21.24	32.36	28.06	128.74***
Eastern	0.58	0.20	0.38	324.06***
Central	0.21	0.37	0.28	57.45***
Western	0.21	0.43	0.35	129.19***
Observations	2,618	1,542	2,301	

Note: *** < 0.01.

4. Empirical results

Table 3 presents the results of the empirical analysis. Since the magnitudes of the coefficients from the MNL model are not straightforward in interpretation (Ma and Abdulai 2016; Zhou et al. 2020), we calculate and present the marginal effects of explanatory variables in Table 3 to ease our understanding and facilitate the discussions. For reference, we present the coefficient estimates of the variables in Table A2 in the Appendix.

4.1 Results from key independent variables

The MNL results show that relative to rural households with the lowest level of income (quintile 1), those at income quintiles 2-5 have a higher probability of using clean fuels but a lower probability of using non-clean fuels for cooking. For example, compared with households at quintile 1, those at quintiles 2 and 5 are 4.8% and 21.7%, respectively, more likely to use clean fuels for cooking. In comparison, those at quintiles 2 and 5 are 5.2% and 19.2%, respectively, less likely to use non-clean fuels for cooking. The findings largely echo the energy ladder theory, emphasizing that households consume more clean fuels and less non-clean fuels when their income increases. Our results that income growth promotes energy use transition are consistent with the existing literature (Alem et al. 2016; Amoah 2019; Jaime et al. 2020; Ma et al. 2019). For example, Ma et al. (2019) found that with increasing off-farm income (the largest contributor of household income), rural households in China tend to consume more clean fuels such as gas and electricity but less non-fuel fuels such as coal. It shows that rural income growth is not significantly correlated with rural households' decisions to use mixed fuels.

Table 3 Marginal effects of income quintiles and minority on cooking fuel choices: MNL model estimates

Variables	Clean fuels (Marginal effects)	Non-clean fuels (Marginal effects)	Mixed fuels (Marginal effects)
Key independent variables			
Income (Base = Quintile 1)			
Quintile 2	0.048 (0.019)**	-0.052 (0.015)***	0.004 (0.019)
Quintile 3	0.097 (0.021)***	-0.118 (0.018)***	0.021 (0.022)
Quintile 4	0.153 (0.019)***	-0.148 (0.017)***	-0.006 (0.020)
Quintile 5	0.217 (0.020)***	-0.192 (0.020)***	-0.024 (0.023)
Minority	-0.065 (0.039)*	-0.013 (0.024)	0.079 (0.035)**
Minority*Quintile 2	0.013 (0.050)	0.007 (0.033)	-0.020 (0.045)
Minority*Quintile 3	0.005 (0.059)	0.010 (0.044)	-0.014 (0.055)
Minority*Quintile 4	0.066 (0.054)	0.051 (0.041)	-0.117 (0.054)**
Minority*Quintile 5	0.141 (0.058)**	-0.077 (0.061)	-0.064 (0.064)
Control variables			
Age	-0.005 (0.001)***	0.001 (0.000)	0.004 (0.001)***
Gender	-0.041 (0.020)**	0.028 (0.018)	0.014 (0.021)
Education	0.028 (0.005)***	-0.029 (0.006)***	0.001 (0.006)
Family size	0.003 (0.003)	-0.016 (0.003)***	0.013 (0.003)***
Dependency ratio	-0.032 (0.012)***	0.007 (0.010)	0.025 (0.012)**
Pollution perception	0.067 (0.007)***	-0.052 (0.007)***	-0.015 (0.008)**
Car ownership	0.125 (0.015)***	-0.038 (0.018)**	-0.087 (0.019)***
Distance	-0.002 (0.000)***	0.001 (0.000)***	0.001 (0.000)***
Eastern	0.157 (0.014)***	-0.142 (0.013)***	-0.015 (0.015)
Central	0.028 (0.016)*	0.010 (0.012)	-0.039 (0.016)**
Observations		6,461	

Note: The reference region is Western. Standard errors are presented in parentheses. * < 0.10, ** < 0.05, and *** < 0.01.

The minority variable is negative and statistically significant in the clean fuel specification (column 2 of Table 3) but is positive and significant in the mixed fuel specification (last column of Table 3). The findings suggest that compared with the Han Chinese households, ethnic minority households are 6.5% less likely to use clean fuels but are 7.9% more likely to use mixed fuels for cooking. To some extent, our results are in line with the results of Yang et al. (2020), who found that ethnic minority households are more likely to use fuelwood or coal (two typical non-clean fuels) for cooking relative to their Han Chinese counterparts in China when other things are equal.

To capture the association between rural income growth among ethnic minority households and cooking fuel choices, we include four variables representing multiplicative interaction terms between the income quintile variables and the minority variable. The results show that the variable representing *Minority*Quintile 5* is negative and statistically significant in column 2 of Table 3. The finding suggests that relative to ethnic minority households with the lowest income level (quintile 1), only those with the highest income level (quintile 5) are 14.1% more likely to use clean fuels for cooking. The coefficients of interaction terms in column 3 are insignificant, even at the 10% significance level, which indicates that rural income growth among ethnic minority households is not associated with their decisions to choose non-clean fuels for cooking. In the last column of Table 3, the significant and positive marginal effect of *Minority*Quintile 4* variable suggests that relative to ethnic minority households with the lowest income level (quintile 1), those at income quintile 4 are 11.7% less likely to mix clean and non-clean fuels for cooking.

Here, we find evidence that the energy ladder theory is potentially not appropriate to explain energy transition among ethnic minority households. Several reasons can help explain the findings, and we discuss three here. First, the ethnic minority people have disadvantages in accessing job markets due to discrimination, language barriers, and unfavorable working skills, and thus, they receive lower income compared with their Han Chinese counterparts (Gustafsson and Shi 2003b; Liu et al. 2019). The finding of the income gap between ethnic minority and Han Chinese households is also supported by the findings in Figure 1. Given this, ethnic minority households may allocate income to other important household activities (e.g., children education, farm, and off-farm business investment, and betrothal gifts) rather than clean cooking fuel consumption. Second, ethnic minority households, no matter poor or rich, may have been used to non-clean fuels like firewood, straw, and dung, which are usually easily available in the places they live (Yang et al. 2020). Third, the cultural differences determine the cooking habits and cooking fuel choice, rather than income levels. Our findings highlight that in addition to increasing the income of ethnic minority households, it is also important to disseminate knowledge about the benefits of energy transition among them when the government makes efforts to promote clean fuel consumption for all.

For robustness check, we estimated a full sample model with an inclusion of a set of multiplicative interactive terms between a rural variable that distinguishes geographical location of sample households, income quintile variables, and ethnic minority variable. The results are presented in Table A3 in the Appendix. The significant marginal effects of the interactive terms suggest that relative to rural ethnic minority households at the income quintile 1, those at the income quintiles 4-5 are more likely to use clean fuels but are less likely to use non-clean fuels. The findings in Table A3 largely echo the findings we estimated using the rural samples and presented in Table 3, confirming the robustness of our estimates. Another interesting finding is the significant marginal effects of the rural variable. The findings suggest that rural households are 8.2% more likely to use non-clean fuels, 29% more likely to use mixed fuels, but are 37.2% less likely to use clean fuels for cooking relative to urban households

4.2 Results from control variables

In addition to income and minority-related variables, the MNL results in Table 3 also show that rural households' decisions to choose cooking fuels are also affected by demographic and socioeconomic factors.

The marginal effects of the age variable are negative and statistically significant in column 2 of Table 3 but positive and significant in the last column of the same table. The findings suggest that with a one year increase in the household heads' age, the probability of using clean fuels for cooking within an "average" household would decrease by 0.5%, while the probability of using mixed fuels would increase by 0.4%. Our finding is in line with the finding of Hou et al. (2018), who showed that increasing household heads' age reduces the probability of using gas for cooking in China. The significant and negative marginal effect of the gender variable in column 2 suggests that relative to female household heads, male household heads are 4.1% less likely to use clean cooking fuels. It is widely confirmed that women than men are more likely to use clean fuels (Liu et al. 2020; Rahut et al. 2016a). Men usually spend less time on housework (e.g., cooking or looking after kids and elders) than women due to the traditional intra-household labor division. Thus, men pay less attention to the health and economic impacts of clean and non-clean fuels, which impedes their clean fuel consumption behaviors (Nwaka et al. 2020).

The educational level of household heads significantly affects cooking fuel choices. Our estimates indicate that rural households are 2.8% more likely to use clean cooking fuels but 2.9% less likely to use non-clean fuels if they have a better education. Better education promotes energy transition has been widely reported in the literature (e.g., Alem et al., 2016; Amoah, 2019; Liu et al., 2020; Mottaleb et al., 2017; Rahut et al., 2017). For example, Amoah (2019) found that households with better-educated heads are more likely to use LPG than charcoal for cooking in Ghana. Better education increases households' recognition and awareness of the negative effects of using non-clean fuels and the advantages of using clean fuels in terms of convenience and efficiency.

The variable representing family size has a significant and negative marginal effect in column 3 and a positive marginal effect in the last column. The findings indicate that households with a relatively larger family size are 1.6% less likely to use non-clean fuels, but they are 1.3% more likely to use mixed fuels for cooking. As family size increases, households switch to mixed cooking fuels to meet the increased demand for energy (Alem et al. 2016; Heltberg 2004; Ngui et al. 2011). Alem et al. (2016) revealed that family size increases the probability of using mixed cooking fuels and decreases the probability of using non-clean biomass fuel in Ethiopia. The dependency ratio variable appears to have a significant impact on cooking fuel choices. We show that rural households with a higher dependency ratio have a 3.2% lower probability of using clean fuels but a 2.5% higher probability of using mixed fuels for cooking. A higher dependency ratio means lower labor availability for income gains within households. Thus, households with a higher dependency ratio choose to use mixed fuels to reduce energy costs as using clean fuels is more costly. For example, some rural households may use straws generated from farm production and collected wood as cooking fuels without paying any costs (Chen et al. 2006). Our findings regarding the association between dependency ratio and household cooking fuel choice are largely in line with the findings of Alem et al. (2016) for Ethiopia and Jaime et al. (2020) for Chile.

The marginal effects of the pollution perception variable are significant in all three specifications. We show that rural households have a 6.7% higher probability of using clean fuels but 5.2% lower probability of using non-clean fuels and 1.5% lower probability of using mixed fuels for cooking if they perceive their residential area suffers from a higher level of air pollution. Jaime et al. (2020) also reported that residents, who are unsatisfied with air quality, would be more likely to use clean fuels such as LPG and electricity for heating and cooking in Chile. Car ownership significantly affects cooking fuel choices. We show that relative to households without owning a car, their counterparts with car ownership are 12.5% more likely to use clean fuels, but are 3.8% and 8.7%, respectively, less likely to use non-clean and mixed fuels. Car ownership is a proxy of household wealth in rural regions of developing countries. Thus, financially performing better households are more likely to use clean fuels than non-clean or mixed fuels for cooking. In their analysis of household cooking fuel choices for sub-Saharan Africa, Rahut et al. (2016) also found that car ownership is positively associated with the consumption of clean fuels, such as electricity, LPG, and kerosene, but is negatively associated with fuelwood consumption.

The distance variable is found to be negatively and significantly associated with the probability of using clean fuels. However, it is positively and significantly related to the likelihood of using non-clean and mixed fuels, which is in line with the studies conducted by Rahut et al. (2016) for Ethiopia, Malawi, and Tanzania, and Liu et al. (2020) for China. A long-distance to markets increases transaction costs and reduces farmers' incentives to purchase and use clean fuels for cooking. For example, natural gas is not available in many rural areas because of high operation costs (e.g., costs of pipes used to connect end-users in rural areas).

Finally, the results show that the regional variables controlling for location fixed effects are significantly different from zero, indicating the existence of spatial effects that affect household cooking fuel choice. Relative to their counterparts residing in Western China (reference region), rural households living in Eastern China are 15.7% more likely to use clean fuels for cooking and 14.2% less likely to use non-clean fuels. In comparison, households living in Central China are 2.8% more likely to use clean cooking fuels but 3.9% less likely to use mixed fuels. Compared with the Western region of China, the Eastern and Central regions are economically performing better, and this is a partial reason that households located in these two regions are more likely to use clean cooking fuels. The findings highlight the importance of including geographic location variables when analyzing household cooking fuel choice. Earlier studies generally agree that the region of residence matters with cooking fuel choice (e.g., Alem et al., 2016; Mottaleb et al., 2017; Paudel et al., 2018; Rahut et al., 2017; Wang and Jiang, 2017).

4.3 Results from urban samples

The existing literature reveals significant differences in household cooking fuel choice between rural and urban households due to a wide range of differences existed in rural and urban regions, such as income levels, infrastructure for fuel transmission, cooking habits, and resource endowments (Hou et al. 2017; Paudel et al. 2018; Rahut et al. 2016b; Wang and Jiang 2017; Wang and Feng 2001). To find out how income growth and ethnic differences influence cooking fuel choices of urban households in China, we also provide evidence estimated for urban household samples. The estimates of the marginal effects are presented in Table A4 in the Appendix. By comparing the results estimated for urban households (Table A4) with the results estimated for rural households (Table 3), we discuss four interesting findings below.

First, our estimates reveal that the impacts of income growth on energy transition are larger for rural households than urban households. We show that relative to their counterparts at income quintile 1, household income increases the probability of clean cooking fuel consumption for urban households by only 3.2-4.7% but increases that for rural households by 4.8-21.7% at income quintiles 2-5. Regarding non-clean cooking fuel consumption, urban households are only 0.4-2.3% less likely to use non-clean cooking fuels, while rural households are 5.2-19.2% less likely to use it when their income increases from quintile 2 to 5. Second, rural income growth has no significant impact on mixed cooking fuel choice, but urban income growth has substantial impacts. Relative to urban households at income quintile 1, those at income quintile 2 are 1.5% less likely to use mixed cooking fuels, and those at income quintiles 4-5 are 2.8-3.9% less likely to use it. Third, compared with the Han Chinese households living in urban areas, the ethnic minority households are more likely to use non-clean cooking fuels, probably influenced by their unique cultures. Fourth, income growth among urban ethnic minority people does not significantly impact their cooking fuel choice.

Beyond the above findings of the key independent variables, our estimates show that some control variables do not have the same impacts on cooking fuel choices of urban households as they have on those of rural households. For example, the family size of urban households is negatively associated with clean cooking fuel choice but is positively related to non-clean cooking fuel choice. Relative to those residing in Western China (reference location), urban households located in Eastern China are more likely to use mixed fuels, and those living in Central China are less likely to use non-clean fuels.

5. Conclusions

Although the existing studies have highlighted the significant role of income growth in determining household cooking fuel choices, little is known about the associations between rural income growth, ethnic differences, and household cooking fuel choice. To address this research gap, this study investigated the impact of rural income growth and ethnic differences on household cooking fuel choices. We considered the presence of fuel-stacking behavior and assumed that households are making exclusive decisions by choosing clean fuels, non-clean fuels, and mixed fuels. The MNL model was utilized to analyze the data of 6,461 rural samples from 2016 CLDS. For comparison, the results estimated using the urban household samples were also presented and briefly discussed.

The MNL estimation results revealed that rural households at income quintiles 2-5 are more likely to use clean cooking fuels and less likely to use non-clean cooking fuels than their counterparts at the income quintile 1 (reference group). Specifically, the marginal effects of household income are to increase the probabilities of clean cooking fuel consumption from 4.8% at quintile 2 to 21.7% at quintile 5, while its marginal effects are to decrease the likelihoods of non-clean fuel consumption from 5.2% at quintile 2 to 19.2% at quintile 5. Our estimates also showed significant differences in cooking fuel choices between the ethnic minority and Han Chinese households. Ethnic minority households are 7.9% more likely to consume mixed fuels and 6.5% less likely to consume clean fuels than Han Chinese households. The interaction term estimates indicated that only ethnic minority households at the highest income level (quintile 5) have a 14.1% higher probability of consuming clean fuels than those at the lowest income quintile 1. The additional estimates for the urban household samples confirm that income growth has larger impacts on rural households' energy transition.

Our findings have practical implications for designing policy instruments devoted to promoting rural energy transition. The finding of the positive impacts of rural income growth on clean cooking fuel choice underscores the importance of government efforts in helping rural people participate in income-generating farm and non-farm activities. In practice, the government can collaborate with extension agents and other industry stakeholders to train rural dwellers with special employment skills. We found that ethnic minority households face difficulties in utilizing clean cooking fuels, and income significantly increases clean cooking fuel use among those households at the highest income quintile 5. The findings suggest that more targeted assistance should be given to ethnic minority households to help increase their income and improve their awareness and recognition of the benefits of using clean cooking fuel. For example, the policymakers could consider providing subsidies for those who are willing to use clean fuel and invest in ancillary facilities, such as constructing biogas digester and solar panels.

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Appendix

Table A1 Distributions of cooking fuel choices

Fuel type	Fuels	Sample size	Percentage
Clean fuels	Liquid gas only	637	24.33
	Electricity only	623	23.80
	Natural gas only	92	3.51
	Methane only	23	0.88
	Solar energy only	1	0.04
	Combining any two clean fuels	1,223	46.72
	Combining any three clean fuels	19	0.73
	Total	2,618	100
Non-clean fuels	Firewood only	1,233	79.96
	Coal only	178	11.54
	Both firewood and coal	131	8.50
	Total	1,542	100
Mixed fuels	One clean fuel and one non-clean fuel	1,327	57.67
	Any three fuels (at least one non-clean fuel)	909	39.50
	Any four fuels (at least one non-clean fuel)	63	2.74
	Any five fuels (at least one non-clean fuel)	1	0.04
	Any six fuels (at least one non-clean fuel)	1	0.04
	Total	2,301	100

Table A2 Impact of income quintiles and minority on cooking fuel choices: MNL model estimates

Variables	Clean fuels (Coefficients)	Non-clean fuels (Coefficients)
Key independent variables		
Income (Base = Quintile 1)		
Quintile 2 (Income)	0.157 (0.108)	-0.260 (0.102)**
Quintile 3 (Income)	0.282 (0.117)**	-0.624 (0.122)***
Quintile 4 (Income)	0.550 (0.109)***	-0.698 (0.118)***
Quintile 5 (Income)	0.818 (0.117)***	-0.865 (0.143)***
Minority	-0.429 (0.215)**	-0.264 (0.156)*
Minority*Quintile 2	0.094 (0.275)	0.083 (0.213)
Minority*Quintile 3	0.053 (0.322)	0.083 (0.287)
Minority*Quintile 4	0.528 (0.301)*	0.543 (0.284)*
Minority*Quintile 5	0.656 (0.316)**	-0.210 (0.411)
Control variables		
Age	-0.029 (0.003)***	-0.009 (0.003)***
Gender	-0.180 (0.110)	0.098 (0.124)
Education	0.095 (0.029)***	-0.144 (0.038)***
Family size	-0.025 (0.016)	-0.110 (0.018)***
Dependency ratio	-0.174 (0.067)***	-0.029 (0.067)
Pollution perception	0.272 (0.038)***	-0.215 (0.047)***
Car ownership	0.660 (0.089)***	0.042 (0.123)
Distance	-0.010 (0.002)***	0.002 (0.001)
Eastern	0.584 (0.080)***	-0.648 (0.093)***
Central	0.198 (0.088)**	0.147 (0.085)*
Constant	0.723 (0.254)***	1.672 (0.277)***
Sample size	6,461	

Note: The reference group is mixed fuels. The reference region is Western. Standard errors are presented in parentheses. * < 0.10, ** < 0.05, and *** < 0.01.

Table A3 Marginal effects of income quintiles and minority on cooking fuel choices of full samples: MNL model estimates

Variables	Clean fuels (Marginal effects)	Non-clean fuels (Marginal effects)	Mixed fuels (Marginal effects)
Key independent variables			
Income (Base = Quintile 1)			
Quintile 2	0.049 (0.012)***	-0.033 (0.009)***	-0.016 (0.012)
Quintile 3	0.085 (0.013)***	-0.083 (0.011)***	-0.003 (0.013)
Quintile 4	0.125 (0.012)***	-0.096 (0.011)***	-0.029 (0.012)**
Quintile 5	0.163 (0.013)***	-0.121 (0.013)***	-0.042 (0.014)***
Minority	-0.175 (0.018)***	0.108 (0.012)***	0.066 (0.018)***
Rural	-0.372 (0.011)***	0.082 (0.012)***	0.290 (0.015)***
Rural*Minority*Quintile 2	0.132 (0.029)***	-0.105 (0.020)***	-0.027 (0.027)
Rural*Minority*Quintile 3	0.125 (0.037)***	-0.100 (0.028)***	-0.025 (0.034)
Rural*Minority*Quintile 4	0.164 (0.032)***	-0.080 (0.026)***	-0.084 (0.033)***
Rural*Minority*Quintile 5	0.227 (0.036)***	-0.175 (0.040)***	-0.053 (0.039)
Control variables			
Age	-0.003 (0.000)***	0.000 (0.000)	0.003 (0.000)***
Gender	-0.052 (0.012)***	0.031 (0.011)***	0.021 (0.013)
Education	0.027 (0.003)***	-0.025 (0.003)***	-0.002 (0.003)
Family size	-0.005 (0.002)**	-0.007 (0.002)***	0.012 (0.002)***
Dependency ratio	-0.020 (0.008)**	0.004 (0.006)	0.015 (0.008)**
Pollution perception	0.055 (0.004)***	-0.042 (0.004)***	-0.013 (0.005)***
Car ownership	0.085 (0.010)***	-0.028 (0.011)**	-0.058 (0.012)***
Distance	-0.002 (0.000)***	0.001 (0.000)***	0.001 (0.000)***
Eastern	0.105 (0.009)***	-0.110 (0.009)***	0.005 (0.010)
Central	0.023 (0.010)**	0.003 (0.008)	-0.025 (0.010)**
Observations		10,696	

Note: The reference region is Western. Standard errors are presented in parentheses. * < 0.10, ** < 0.05, and *** < 0.01.

Table A4 Marginal effects of income quintiles and minority on cooking fuel choices of urban households: MNL model estimates

Variables	Clean fuels (Marginal effects)	Non-clean fuels (Marginal effects)	Mixed fuels (Marginal effects)
Key independent variables			
Income (Base = Quintile 1)			
Quintile 2	0.034 (0.012)***	-0.019 (0.011)*	-0.015 (0.007)**
Quintile 3	0.032 (0.014)**	-0.023 (0.013)*	-0.009 (0.008)
Quintile 4	0.044 (0.016)***	-0.004 (0.012)	-0.039 (0.012)***
Quintile 5	0.047 (0.021)**	-0.019 (0.019)	-0.028 (0.012)**
Minority	-0.073 (0.013)***	0.074 (0.007)***	-0.001 (0.011)
Minority*Quintile 2	-0.002 (0.022)	-0.011 (0.013)	0.014 (0.018)
Minority*Quintile 3	0.029 (0.027)	-0.023 (0.017)	-0.006 (0.024)
Minority*Quintile 4	0.379 (22.516)	-0.025 (1.988)	-0.354 (24.504)
Minority*Quintile 5	0.342 (26.079)	0.017 (2.302)	-0.359 (28.381)
Control variables			
Age	-0.001 (0.000)***	0.000 (0.000)	0.001 (0.000)**
Gender	-0.036 (0.010)***	0.017 (0.007)**	0.020 (0.008)**
Education	0.012 (0.002)***	-0.009 (0.002)***	-0.003 (0.002)*
Family size	-0.012 (0.002)***	0.003 (0.001)**	0.008 (0.001)***
Dependency ratio	-0.004 (0.007)	0.005 (0.005)	-0.001 (0.005)
Pollution perception	0.028 (0.004)***	-0.017 (0.003)***	-0.011 (0.003)***
Car ownership	0.021 (0.009)**	-0.010 (0.007)	-0.011 (0.007)
Distance	-0.003 (0.000)***	0.002 (0.000)***	0.001 (0.000)***
Eastern	0.053 (0.014)***	-0.076 (0.013)***	0.023 (0.007)***
Central	0.014 (0.011)	-0.013 (0.007)*	-0.002 (0.009)
Observations		4,235	

Note: The reference region is Western. Standard errors are presented in parentheses. * < 0.10, ** < 0.05, and *** < 0.01.