The demand for coal among China's rural households: Estimates of price and income elasticities

Meixuan Teng[1,2,3,4], Paul J. Burke[5], Hua Liao[1,2,3,4,6*]

1. School of Management and Economics, Beijing Institute of Technology, Beijing 100081, China.
2. Center for Energy and Environmental Policy Research, Beijing Institute of Technology, Beijing 100081, China.
3. Sustainable Development Research Institute for Economy and Society of Beijing, Beijing 100081, China.
4. Beijing Key Laboratory of Energy Economics and Environmental Management, Beijing 100081, China.
5. Arndt-Corden Department of Economics, Australian National University, Canberra, ACT 2601, Australia.
6. Collaborative Innovation Center of Electric Vehicles in Beijing, Beijing 100081, China.

*Corresponding author: Dr. Hua Liao is professor and Deputy-Director of the Center for Energy and Environmental Policy Research (CEEP), Beijing Institute of Technology (BIT).
E-mail: hliao@bit.edu.cn

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Abstract: China’s residential sector has experienced rapid electrification and gasification. Among rural households, however, coal still accounts for a large share of energy use, especially in the north. Use of coal for cooking and heating brings large health and pollution risks. From a theoretical viewpoint, economic tools such as taxes and subsidies have the potential to play a crucial role in addressing this issue. In this paper, a provincial-level dataset is used to estimate the price and income elasticities of aggregate coal demand by rural households. We find that coal is a non-Giffen inferior good for the rural household sector. This means that future income growth may help to induce switching from coal. Demand is becoming more price elastic as rural incomes grow. We also find that rural residential coal demand is more price- and income-responsive in the south than the north, perhaps because of fewer substitution options in the north. Our results provide benchmarks and parameters for policy simulation research.

Key words: coal demand; price elasticity; income elasticity; China; rural household

JEL classification: O13; Q41; Q48; R21

1. Introduction

During the last four decades, China has experienced rapid electrification and gasification (Arora et al., 2016), achieving the goal of electricity for all in 2015 (NEA, 2015). On average, the consumption share of solid fuels such as coal and traditional biomass has decreased dramatically because of factors such as income growth and improved energy infrastructure. However, use of traditional fuels for cooking and heating remains pervasive in rural areas (Chen et al., 2018). Rural dependence on solid fuels is one of the most important energy poverty issues in the country (Tang and Liao, 2014).

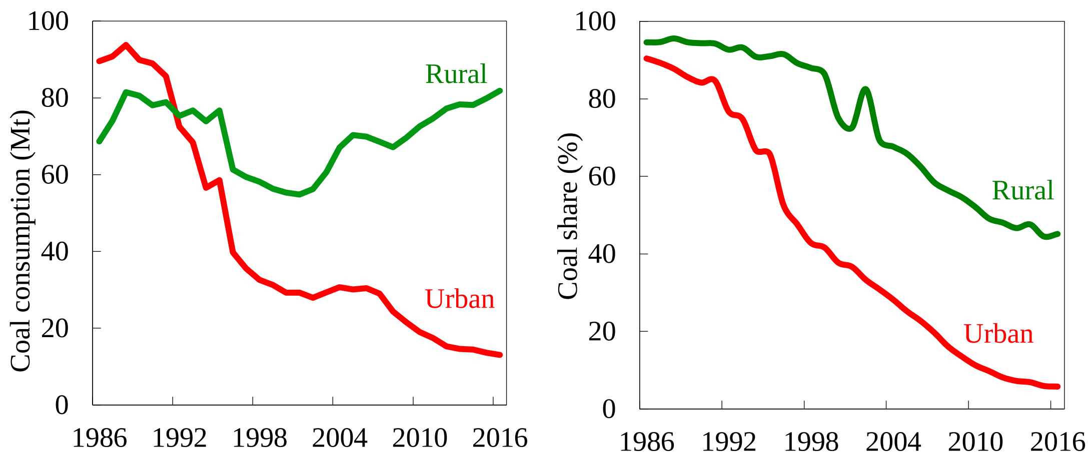
As of 2016, coal accounted for less than 6% of the commercial energy use of urban households (Fig. 1). This figure was around 45% for rural households (Fig. 1). In terms of quantity, coal consumption in rural areas climbed to 82 Mt in 2016, up from 55 Mt in 2000 (NBS, 2018). Rural coal consumption varies dramatically by region (Wu et al., 2017). According to our dataset (described in detail in Section 2), the north accounts for around 82% of the total rural household coal consumption in China in 2012.

Coal combustion by households produces a large number of pollutants such as PM10, PM2.5, and black carbon. Research on the Global Burden of Disease (2017) concludes that around 9.3% of China's premature mortality in 2015 (600,000 deaths) was caused by indoor air pollution due to solid fuel use (biomass and coal). Household solid fuel use is also a major source of outdoor air pollution (Chafe, 2014; Chen et al., 2017; Liao et al., 2017), and contributes 25% of China's black carbon emissions, a key greenhouse gas (Mehta, 2016; Sun et al., 2017). Dispersed coal use for heating in rural households is one of the major sources of indoor air pollution, especially in northern China (Li et al., 2016; Liu et al, 2017; Zhang et al, 2017).

Under pressure to act on pollution and climate change (Lindholt and Glomsrød, 2018), China's government has been aiming to reduce coal use and improve coal-use efficiency. In 2016, it set a target cap of 4.1 billion tons of coal consumption as of 2020. This target was allocated to coal-intensive sectors and local authorities. The household sector was not the focus. Since 2017, the central government has attached more specific importance to controlling ambient air pollution, which is included as one of its three large battles (together with eliminating poverty and reducing financial risks) over the period to 2020. The government has also implemented a strategic rural development plan, with a focus on improving the rural living environment. Since 2017, the government launched an ambitious campaign to reduce coal use for heating and to transition to natural gas and electricity, especially in areas with heavy air pollution such as the Beijing-Tianjin-

Hebei region. Although some rural households have access to natural gas, they are often reluctant to use it due to its high cost.

From a theoretical point of view, tax and subsidy policies could play a larger role in a transition away from rural coal use. The success of such policies is dependent on the price and income elasticities of demand for this product. In this paper, we use a provincial-level dataset on average rural household coal consumption and average coal prices, constructed using the *China Yearbook of Rural Household Survey (CYRHS)* and the *China Yearbook of Household Survey (CYHS)*, to provide what is perhaps the first investigation of the price and income elasticities of aggregate coal use by rural residences in China. The survey data are available annually from the National Bureau of Statistics (NBS) of China.



(1-1) (1-2)

Fig. 1 Coal consumption and coal share of commercial energy used by China's household sector
Data sources: Calculated based on latest versions of the China Energy Statistical Yearbook (CESY), which are released by the National Bureau of Statistics of China (NBS). Rural coal share is calculated as the share of energy from coal in total rural household energy consumption. Energy is measured in thermal-equivalent terms. Energy consumption for transportation is excluded.

In northern China, around 90% of the coal used by households is for heating. Biomass is seldom used for heating due to its inconvenience and technical constraints (Zhu et al., 2018; NRDC, 2017). In the south, less heating is needed, and household coal use is mainly for cooking (Wang and Jiang, 2017). In general, there are better energy substitutes for cooking (e.g. electricity, natural gas, biomass) than there currently are for household heating in rural areas in the north, meaning that it might be expected that rural household coal demand is more price sensitive in the south than in the north. We will explore if this is the case.

The effect of incomes on rural household coal demand is of substantial interest, and *a priori* expectations are uncertain. Higher incomes might allow rural households to boost their use of coal, which would imply a positive income elasticity. On the other hand, higher incomes may induce substitution to higher-quality energy sources, which could imply a negative income elasticity.

In prior work, Burke and Liao (2015) investigated the coal price elasticity of demand at an aggregate level in China. They used provincial data and found that the price elasticity had increased but remained inelastic, and was from −0.3 to −0.7 as of 2012. It is important to note, however, that the price and income elasticities of coal demand may vary by sector. Households or private companies may be more sensitive to price since they are directly responsible for their expenditures. State-owned enterprises may be less price-sensitive given the less-direct incentives that decision makers in these enterprises face (Fan et al, 2007). To date, the coal price elasticity in China's rural household has remained unclear.

Using data from a large micro-level survey by the National Bureau of Statistics, Cao et al. (2016) examined the price elasticity of demand for coal in urban areas, finding that poor urban households are sensitive to the coal price. Because residential coal consumption in rural areas is much larger than that in urban areas, our paper's focus on rural households is important. The results of Cao et al. (2016) are nevertheless highly relevant given that the average income of poor urban households is approximately equal to that of the average rural household (NBS, 2017).

Li and Li (2018) provided empirical evidence that aggregate energy demand becomes more price elastic during the transition to a more market-oriented economy. Cattaneo et al. (2011) studied industrial coal demand in provincial China. However, they did not estimate the price elasticity, and may have underestimated the income elasticity given that the coal price increased during their study period. While some prior papers have investigated household fuel transitions in specific provinces or villages (Chen et al., 2006; Zhang et al., 2014; Zhi et al., 2017), our research takes a national perspective. We will relate our estimates to those in prior studies in section 4.

2. Data and method

2.1 Data descriptions

The aggregate coal consumption data available in Statistical Yearbooks in China are somewhat unreliable, especially at the provincial level (Akimoto et al, 2006; Liao and Wei, 2011). This is due to reasons such as there being many small local coal mines, and no border checks between provinces.

Data reported by provincial authorities are subject to issues of statistical corruption (Sinton, 2001; Akimoto, et al., 2006; Liu, et al., 2009), with the sum of the provincial totals typically differing from the national total (Shan, et al., 2016). Data on provincial coal use by the residential sector are usually a balance term in the energy accounts. Provincial data on rural coal use are typically considered to be underestimates (Zhi et al., 2017).

For the above reasons, we do not use the provincial-level coal data in the *China Energy Statistical Yearbook (CESY).* We instead turn to data from the National Household Survey, which cover around 160,000 households in 1,800 counties each year. The National Bureau of Statistics (NBS) of China conducts this survey and releases the *China Yearbook of Household Survey* (*CYHS*) on an annual basis. The *CYHS* data are bottom-up data from household surveys, and are likely to be more reliable. Survey agencies in China use data quality control systems for these data (NBS, 2016).

An issue making price comparisons challenging is that various types of coal are consumed by the rural residential sector. The prices of coking coal, steam coal, and dispersed coal are quite different from one another. In addition, quality differences and transport costs also contribute to variation in coal prices across China. Coal reserves are mainly concentrated in provinces such as Shanxi, Shaanxi, Inner Mongolia, and Guizhou. Based on the survey yearbooks, we constructed a comprehensive measure of the average price of coal paid by rural residences in each province.

To create a proxy for the rural household average coal price for each province, we divide coal expenditure by the coal consumption quantity, using data from the *CYHS*. The details are as follows. The *CYHS* reports household expenditure on firewood, straw, coal, and liquefied petroleum gas (LPG). We made the simplifying assumption that expenditure on firewood and straw is zero given that these commodities are often obtained outside markets. We then deducted expenditure on LPG, arriving at estimated expenditure on coal. We divided by the quantity of coal consumed to arrive at an average price, in *yuan* per kilogram. Household expenditure data from the *CYHS* are often considered to be of reasonable quality (Muller and Yan, 2018).

The measure of coal consumption that we use only includes direct use of primary coal and coal products. It does not include indirect consumption of final energy types or products produced using coal, such as electricity. By dividing expenditure (in *yuan*) by quantity of coal consumption (in kilograms), our price measure is a weighted average for coal of various qualities and types. Our regression approach will include province fixed effects to control for the differences in average coal quality between provinces. Estimations will thus use the *within* variation in the provincial data (i.e. variation over time within each province).

Rural household coal consumption in some provinces – Shanghai, Guangxi, Hainan, Hong Kong, Macao, Taiwan, and Tibet – is extremely low or data are missing, so we exclude these provinces from our analysis. Our analysis thus covers 27 provincial-level administrative units ("provinces" for short). In our data checking, we observed likely errors in the average coal price for Fujian in 2011 and Guangdong and Zhejiang in 2011 and 2012. We replaced these observations with a proxy that we estimated using the growth rate of the average price in neighboring provinces.

Differences between the *CYHS* and *CESY* data are shown in Fig. 2. Many of the dots are far from the 45° line. For example, the Bureau of Statistics of Hebei Province reports coal consumption in rural areas is 8.1 Mt, while the NBS survey data indicates 13.7 Mt.

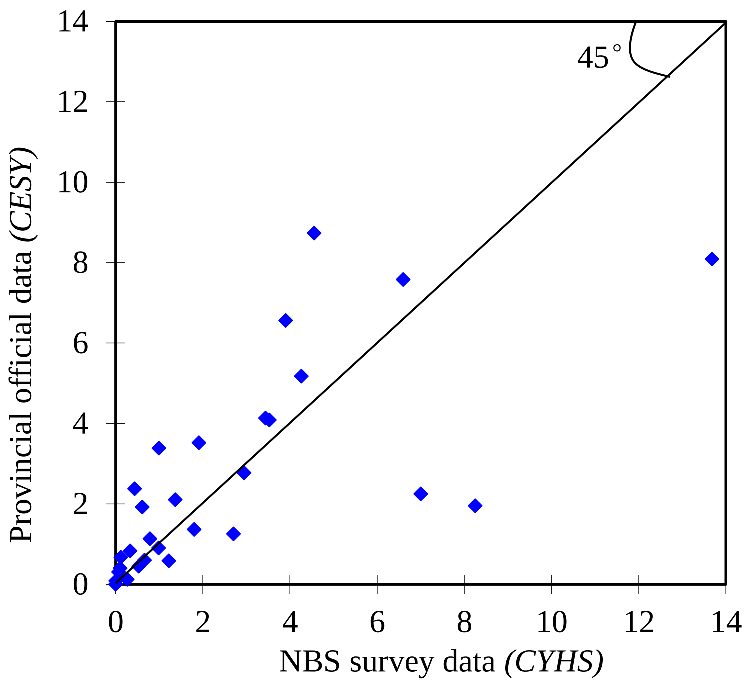


Fig. 2 Residential coal consumption in rural areas by province in 2012 (Mt).

Note: Each dot is a province. NBS is the National Bureau of Statistics of China.

Fig. 3 shows the average rural residential coal price and coal consumption by province in 2012 (3-1), and how the average real rural residential coal price has varied over time (3-2). A negative cross-province association can be seen: rural residences in provinces with low prices tend to consume more coal. A large increase in the average price during 2003–2011 can be observed as a result of the coal price growing faster than inflation. This was in large part due to strong growth in demand for coal for electricity generation and industrial processes (alternative final end users of coal).

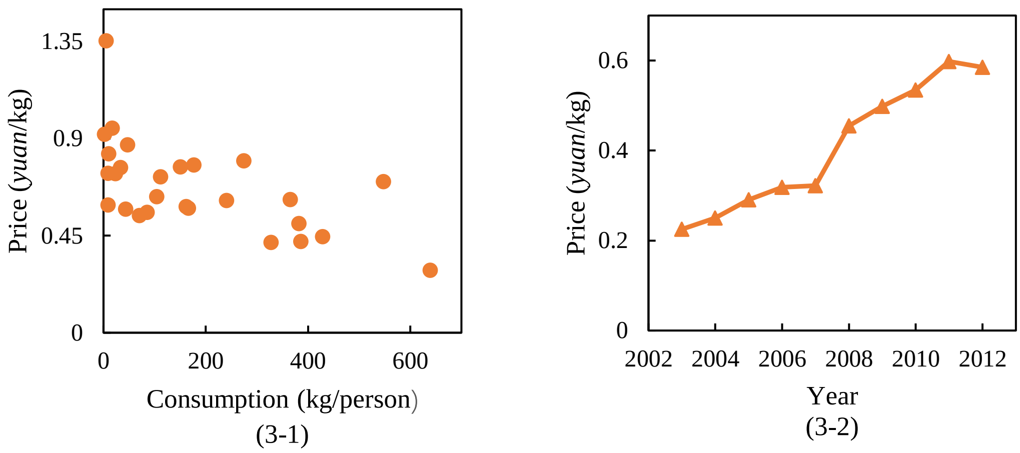


Fig. 3 Real coal price and consumption among rural residences in China, 2012

Note: 3-1: Consumption is shown on the *x*-axis, in line with the standard presentation of a demand function. 3-2: Shows how the average real rural residential coal price of the whole nation has varied over time according to data recorded in *China Yearbook of Household Survey*.

Some of the inequalities in China are visible at the regional level (Wroblowský and Yin, 2016; Wu et al., 2017). Fig. 4 shows per capita rural household coal consumption and income in rural areas in 2012 by province. There are sizeable differences between the north and south, with rural household coal use in the northwest inland areas exceeding that in the southeast coastal areas, in part due to heating requirements and resource endowments. The average annual per capita rural residential consumption volume of coal exceeded 100 kg in the northwest inland areas, while in some southeast coastal provinces it was below 10 kg. There are also observable differences in incomes between regions: provinces located in the southeast tend to have higher per capita incomes.

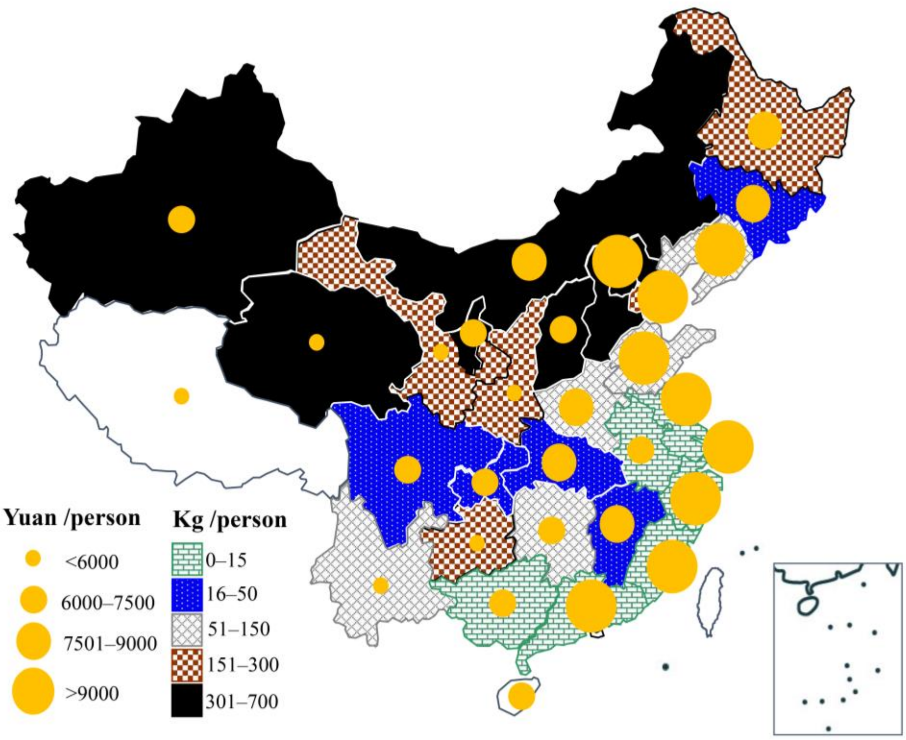


Fig. 4 China's rural per capita coal consumption and per capita net income in 2012.
Data source: *China Yearbook of Household Survey (CYHS)*. Data for coal consumption for Taiwan, Hong Kong, Macao, Tibet, and Hainan are not available.
Note: This is a schematic map and does not implicate definite boundaries.

Table 1 shows descriptive statistics and our sources of data. The main sources include the *CYRHS*, *CYHS, China Rural Statistical Yearbook (CRSY)*, *China Population Statistics Yearbook (CPSY)*, and *China Statistical Yearbook (CSY)*. Both the price of coal and per capita income have been deflated using the provincial rural consumer price index, and are in year-2003 terms. The energy expenditure data are not yet available for 2013 onwards, restricting our sample to 2003–2012. There are no missing data, so our panel is balanced. The number of observations is 270.

Table 1 Sources of data and descriptive statistics of variables

Variable	Description	Mean	Std. Dev.	Min	Max
$C_{p,t}$	Per capita rural residential coal consumption (kg/person)[a]	171	149	2	779
$P_{p,t}$	Real average coal price paid by rural residences (*yuan*/kg; 2003 prices)[a]	0.45	0.21	0.13	1.40

Variable	Description	Mean	Std. Dev.	Min	Max
$Y_{p,t}$	Real rural per capita net income (*yuan*/person; 2003 prices)[b]	4122	1970	1565	12053
$T_{p,t}$	Average temperature in January (degrees Celsius)[c]	-1.22	8.07	-20.9	15.8

Note: [a] *China Yearbook of Rural Household Survey* (2003–2012). [b] *China Rural Statistical Yearbook* (2003–2012). [c] *China Statistical Yearbook* (2003–2012). *p* = province. *t* = year.

2.2 Model specifications

Building on existing research, we establish the following regression model to estimate the price elasticity of demand for coal among China's rural residences. We prefer a fixed-effects specification to control for time-invariant factors that may affect rural residential coal demand at the provincial level (e.g. differences in climate). t is a time trend that ranges from 1 in 2003 to 10 in 2012. We control for the average temperature of provincial capitals in January, $T_{p,t}$, as colder weather is likely to lead to greater residential demand for coal in rural areas. δ_p refers to provincial fixed effects. $\varepsilon_{p,t}$ is an error term. β_1 is the estimation of the price elasticity, while β_2 is the income elasticity.

$$lnC_{p,t} = \beta_1 lnP_{p,t} + \beta_2 lnY_{p,t} + \gamma t + T_{p,t} + \delta_p + \varepsilon_{p,t} \tag{1}$$

In order to investigate if the effect of coal prices on rural residential coal consumption has varied over income, we interact the log coal price with log per capita income in Eq. (2). We deduct the sample mean from log income in this specification so as to allow the price elasticity at each specific per capita income level (*i*) to be estimated as $\beta_1 + \beta_3 * \left(lnY_i - \overline{lnY}\right)$. In Eq. (3) we include a quadratic term of log per capita income to allow for a nonlinear effect of log per capita income. The income elasticity is then $\beta_2 + 2\beta_4 * lnY_i$.

$$lnC_{p,t} = \beta_1 lnP_{p,t} + \beta_2 lnY_{p,t} + \beta_3 lnP_{p,t} * lnY_{p,t} + \gamma t + T_{p,t} + \delta_p + \varepsilon_{p,t} \tag{2}$$

$$lnC_{p,t} = \beta_1 lnP_{p,t} + \beta_2 lnY_{p,t} + \beta_4 lnY_{p,t} * lnY_{p,t} + \gamma t + T_{p,t} + \delta_p + \varepsilon_{p,t} \tag{3}$$

Due to the fact that adjustments in coal use are likely to take time, we also explore adding lagged coal price and income terms to the models:

$$lnC_{p,t} = \beta_1 lnP_{p,t} + \beta_2 lnY_{p,t} + \beta_5 lnP_{p,t-1} + \beta_6 lnY_{p,t-1} + \gamma t + T_{p,t} + \delta_p + \varepsilon_{p,t} \tag{4}$$

$$lnC_{p,t} = \beta_1 lnP_{p,t} + \beta_2 lnY_{p,t} + \beta_5 lnP_{p,t-1} + \beta_6 lnY_{p,t-1} + \beta_3 lnP_{p,t} * lnY_{p,t}$$
$$+\beta_7 lnP_{p,t-1} * lnY_{p,t-1} + \gamma t + T_{p,t} + \delta_p + \varepsilon_{p,t} \tag{5}$$

We also explore whether the price elasticity of rural residential coal demand varies by region. To do so, we use a dummy variable (*D*) for the north of China[1], as follows:

$$lnC_{p,t} = \beta_1 lnP_{p,t} + \beta_2 lnY_{p,t} + \beta_8 D_p lnP_{p,t} + \gamma t + T_{p,t} + \delta_p + \varepsilon_{p,t} \quad (6)$$

$$lnC_{p,t} = \beta_1 lnP_{p,t} + \beta_2 lnY_{p,t} + \beta_8 D_p lnP_{p,t} + \beta_9 D_p lnY_{p,t} + \gamma t + T_{p,t} + \delta_p + \varepsilon_{p,t} \quad (7)$$

$$lnC_{p,t} = \beta_1 lnP_{p,t} + \beta_2 lnY_{p,t} + \beta_3 lnP_{p,t} * lnY_{p,t} + \beta_8 D_p lnP_{p,t} + \beta_{10} D_p lnP_{p,t} * lnY_{p,t} + \gamma t + T_{p,t} + \delta_p + \varepsilon_{p,t} \quad (8)$$

$$lnC_{p,t} = \beta_1 lnP_{p,t} + \beta_2 lnY_{p,t} + \beta_4 lnY_{p,t} * lnY_{p,t} + \beta_8 D_p lnP_{p,t} + \beta_9 D_p lnY_{p,t} + \beta_{11} D_p lnY_{p,t} * lnY_{p,t} + \gamma t + T_{p,t} + \delta_p + \varepsilon_{p,t} \quad (9)$$

where $D = \begin{cases} 1, \text{ provinces located in the north of China} \\ 0, \text{ provinces located in the south of China} \end{cases}$

Rural households account for around 2% of China's total coal consumption (NBS, 2017). Coal demand by rural households is thus unlikely to have a significant effect on coal prices given that there are many other demand-side participants in the market. We thus assume that the risk of reverse causation in our regressions is low. If so, our estimations will provide demand-side elasticities.

We have a sample of 270, which is reasonably large. The normality of residuals assumption is not needed in situations in which the sample is sufficiently large (> around 200), as the Central Limit Theorem ensures that the distribution of disturbance terms will approximate normality (Wooldridge, 2006).

We did not consider the cross-price elasticity between coal and other fuels due to data unavailability reasons:

1) Traditional biomass such as straw and firewood are widely used and self-supplied in rural China. It is difficult to estimate a price or shadow price for these non-commercial fuels.

2) Liquefied petroleum gas and natural gas are not available in many rural areas. Only 22% of the rural population has access to gas (MHURD, 2017).

3) Households faced little variation in nominal electricity prices over 1998–2012, as the residential electricity price has been highly regulated by the government.

The cross-price elasticity issue may be suited to being studied using micro data in the future.

[1] In this paper, the north includes Beijing, Tianjin, Hebei, Shanxi, Inner Mongolia, Liaoning, Jilin, Heilongjiang, Shandong, Henan, Shaanxi, Gansu, Qinghai, Ningxia, and Xinjiang. The south includes Jiangsu, Zhejiang, Anhui, Fujian, Jiangxi, Hubei, Hunan, Guangdong, Chongqing, Sichuan, Guizhou, and Yunnan.

3. Results and discussion

Prior to proceeding to our estimations, we carried out stationarity tests. Im, Pesaran and Shin (2003) tests were employed, with the null hypothesis of all provinces having unit toots rejected for all variables. Cross-sectional means were deducted in these tests, and trends but no lags were included. We thus consider the variables to be stationary. We then conducted a Pesaran (2004) test for cross-sectional dependence. The results indeed provide evidence of cross-sectional dependence. We consequently present results using Driscoll and Kraay (1998) standard errors, which are robust to heteroscedasticity, serial correlation, and possible cross-sectional dependence. The unit root test results, together with a correlation table and residual analysis, are shown in Appendix A.

The regression results for the full sample are shown in Table 2, and the price and income elasticities from these estimates in Table 3. The first three columns of each table show the results of the static model regression, while the latter two are the results of a one-year lag.

As Table 2 shows, the mean aggregate price elasticity of demand for coal by rural households is estimated as –1.0 using the static regression model. Using model 2, the price elasticity evaluated at the sample-mean of the logarithm of per capita rural income is estimated at –1.2. In absolute value terms, the estimated price elasticity becomes larger as household incomes rise: when province-average real rural per capita net income increases from 1,500 to 8,000 *yuan* per year, the average price elasticity increases from –0.5 to –1.8, i.e. becomes price elastic (Table 3).

When lags are considered, insignificance appears in models (4)–(5) for the current and one-year lag terms of price and income. However, the price and income variables are each jointly significant. We find the two-year price elasticity is –1.1, slightly larger than the same-year (static) elasticity. The two-year price and income elasticities are larger than those for the one-year elasticities, consistent with economic theory (Samuelson, 1947).

Per capita income is found to have a remarkable impact on rural household coal consumption: the mean elasticity is estimated at –1.0. Because both the price and income elasticities of demand are negative, rural household coal is a non-Giffen inferior good at the aggregate level. A negative income elasticity of demand is consistent with findings on the national-level energy ladder: households tend to switch from traditional fuels to transition fuels, such as coal and kerosene, and then to modern energy, such as natural gas and electricity, as incomes increase (Burke, 2013), in part due to greater convenience (Ekholm et al., 2010).

Considering a quadratic term of log income per capita, we find that the income elasticity of demand becomes more negative as net income increases. The demarcation point between a positive and a negative point estimate is at around 2,300 *yuan* per capita per year (model 3 of Table 2); when per capita rural incomes exceed this point, the income elasticity tends to become negative. We compare estimations with results using random effects estimation in the base of Table 2, finding relatively minor differences in both models, especially for the price elasticities. The income elasticities based on random effect specifications are slightly smaller (in absolute-value terms).

Table 2 Estimated models of rural residential coal demand

	(1)	(2)	(3)	(4)	(5)
Model		Static		One-year lag	
Ln coal price$_{p,t}$	-1.02***	-1.22***	-1.21***	-1.24***	-1.42***
	(0.17)	(0.17)	(0.22)	(0.17)	(0.23)
Ln coal price$_{p,t-1}$				0.19	0.20
				(0.16)	(0.15)
Ln income$_{p,t}$	-1.03**	-0.97**	11.14***	-1.16	-1.94
	(0.33)	(0.42)	(1.48)	(0.88)	(1.09)
Ln income$_{p,t-1}$				-0.24	0.58
				(0.83)	(1.09)
Time trend$_t$	0.15***	0.10**	0.14***	0.17***	0.13***
	(0.03)	(0.03)	(0.04)	(0.02)	(0.03)
Temperature$_{p,t}$	-0.03**	-0.04**	-0.04**	-0.05***	-0.06***
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Ln coal price$_{p,t}$*Ln income$_{p,t}$		-0.81***			-0.58**
		(0.12)			(0.19)
Ln coal price$_{p,t-1}$*Ln income$_{p,t-1}$					-0.24
					(0.24)
Ln income$_{p,t}$*Ln income$_{p,t}$			-0.72***		
			(0.08)		
Province fixed effects	Yes	Yes	Yes	Yes	Yes
R^2 (within)	0.33	0.49	0.44	0.39	0.52
Observations	270	270	270	243	243
Provinces	27	27	27	27	27
Price elasticity					
Specification 1: As above	-1.02***	-1.22***	-1.21***	-1.05***	-1.22***
Specification 2: Random effects	-1.07***	-1.26***	-1.25***	-1.12***	-1.25***
Income elasticity					
Specification 1: As above	-1.03**	-0.97**	-0.64	-1.40***	-1.36***
Specification 2: Random effects	-0.58	-0.88***	-0.29*	-0.62	-1.01***

Note: *** Statistical significance at 1%. ** Statistical significance at 5%. * Statistical significance at 10%. Driscoll-Kraay standard errors are used in both fixed and random effects specifications, shown in parentheses. Models 2 and 5: Mean Ln income has been subtracted from the interacted

Ln income term. The base of the table evaluates the elasticities at the mean Ln income per capita.

Our results indicate that the average temperature of the provincial capital in January has a negative impact on per capita rural residential coal consumption. This accords with the fact that more coal is likely to be used for heating in cold winters. As of 2012, a one-degree Celsius decline in average January temperature typically leads to about a 3.3-kilogram increase in per capita consumption of coal by rural residences.[2]

Table 3 Estimates of price and income elasticities based on Table 2 (fixed effects).

Model	(1)	(2)	(3)	(4)	(5)
	Static			One-year lag	
Price elasticity	-1.02***		-1.21***	-1.05***	
Price elasticity (*Y*=1500)		-0.48***			-0.47
Price elasticity (*Y*=3000)		-1.05***			-1.05***
Price elasticity (*Y*=5000)		-1.46***			-1.47***
Price elasticity (*Y*=8000)		-1.84***			-1.85***
Income elasticity	-1.03**	-0.97**		-1.40***	-1.36***
Income elasticity (*Y*=1500)			0.68		
Income elasticity (*Y*=3000)			-0.33		
Income elasticity (*Y*=5000)			-1.06**		
Income elasticity (*Y*=8000)			-1.73***		

Note: *** Statistical significance at 1%. ** Statistical significance at 5%. * Statistical significance at 10%. *Y* represents income level per capita (year-2003 prices).

As shown in Tables 4 and 5, results with region dummy interactions provide evidence of differences in the average price elasticity for the north and the south. The price elasticity of demand for coal by rural residences is estimated to be about –0.4 in the north and –1.8 in the south when mean household per capita net income is 5,000 *yuan*. This is in line with our expectation, as there is often little in the way of alternatives for heating in rural areas in the north. The finding suggests that price tools such as a tax on coal would have proportionately smaller effects on coal reduction in the north.

For the income elasticity, we obtain a positive but insignificant estimate for northern China (model

[2] Based on our estimation, per capita annual residential rural coal demand will increase about 3% when the average provincial capital January temperature declines by one degree Celsius. In 2012, the average per rural household demand for coal was about 425 kilograms according to the *China Yearbook of Household Survey*. On average, there were 3.9 people per household in rural China in 2012 according to the NBS of China.

7). If we introduce a quadratic, the results show that the income elasticity in the north switches from positive to negative at around per-capita income of 4,200 *yuan* and becomes more statistically significant when income increases. It drops to –0.9 (10% significance) when income climbs to 25,000 *yuan*. Perhaps, when rural incomes in the north are low, income growth leads to households using more coal for heating. The income elasticity in the south is around –1.6 and statistically significant, which means that coal demand in rural areas of the south will tend to decline as a result of income growth. It is thus perhaps less urgent for policymakers to focus on reducing residential rural coal use in the south given that it is a fair expectation that incomes will continue to grow.

Table 4 Estimated models of household coal demand, with region interactions

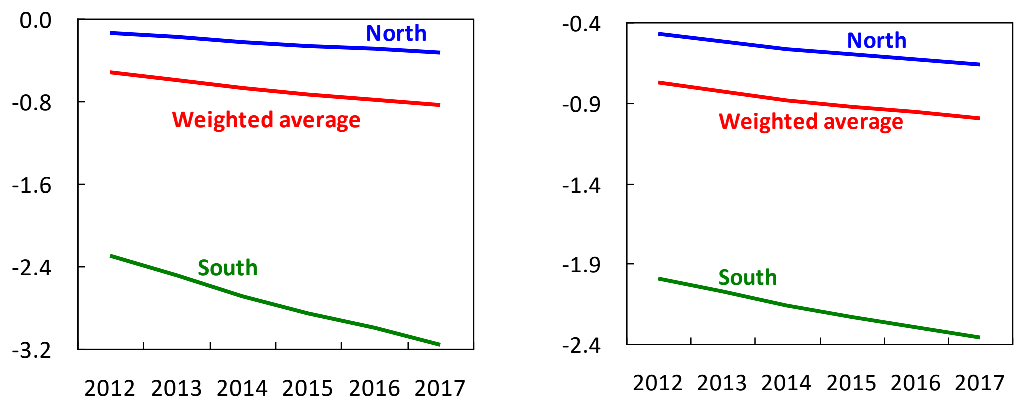
Model	(1)	(6)	(7)	(8)	(9)
Ln coal price$_{p,t}$	-1.02***	-1.13***	-0.32	-1.51***	-0.93***
	(0.17)	(0.19)	(0.29)	(0.05)	(0.10)
Ln income$_{p,t}$	-1.03**	-0.20	-1.64***	-0.28	17.14***
	(0.33)	(0.41)	(0.30)	(0.40)	(1.15)
Time trend$_t$	0.15***	0.03	0.04	0.01	0.08***
	(0.03)	(0.04)	(0.03)	(0.03)	(0.02)
Temperature$_{p,t}$	-0.03**	-0.02	-0.01	-0.03*	-0.02*
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Ln coal price$_{p,t}$*Ln income$_{p,t}$				-0.94***	
				(0.13)	
Ln income$_{p,t}$*Ln income$_{p,t}$					-1.11***
					(0.08)
Ln coal price$_{p,t}$*North$_p$		1.06***	-0.25	1.25***	0.23
		(0.11)	(0.25)	(0.13)	(0.19)
Ln income$_{p,t}$*North$_p$			2.08***		-12.76***
			(0.43)		(0.88)
Ln coal price$_{p,t}$*Ln income$_{p,t}$*North$_p$				0.43***	
				(0.12)	
Ln income$_{p,t}$* Ln income$_{p,t}$ *North$_p$					0.85***
					(0.06)
Province fixed effects	Yes	Yes	Yes	Yes	Yes
R^2 (within)	0.33	0.58	0.63	0.72	0.75
Observations	270	270	270	270	270
Provinces	27	27	27	27	27

Note: *** Statistical significance at 1%. ** Statistical significance at 5%. * Statistical significance at 10%. Driscoll-Kraay standard errors are shown in parentheses. Model 8: The sample mean has been subtracted from log income in the interaction terms.

Table 5 Estimates of price and income elasticity by region and income level based on Table 4.

Model	(1)	(6)	(7)	(8)	(9)
Price elasticity	-1.02***				
Price elasticity in South		-1.13***	-0.32		-0.93***
Price elasticity in North		-0.07	-0.57***		-0.70***
Price elasticity in South (*Y*=1500)				-0.65***	
Price elasticity in South (*Y*=3000)				-1.31***	
Price elasticity in South (*Y*=5000)				-1.79***	
Price elasticity in South (*Y*=8000)				-2.24***	
Price elasticity in North (*Y*=1500)				0.20	
Price elasticity in North (*Y*=3000)				-0.16	
Price elasticity in North (*Y*=5000)				-0.42**	
Price elasticity in North (*Y*=8000)				-0.66***	
Income elasticity	-1.03**	-0.20		-0.28	
Income elasticity in South			-1.64***		
Income elasticity in North			0.44		
Income elasticity in South (*Y*=1500)					0.87**
Income elasticity in South (*Y*=3000)					-0.68*
Income elasticity in South (*Y*=5000)					-1.82***
Income elasticity in South (*Y*=8000)					-2.86***
Income elasticity in North (*Y*=1500)					0.56
Income elasticity in North (*Y*=3000)					0.19
Income elasticity in North (*Y*=5000)					-0.08
Income elasticity in North (*Y*=8000)					-0.32
Income elasticity in North (*Y*=15000)					-0.65
Income elasticity in North (*Y*=25000)					-0.92*

As noted, most rural residential coal consumption (82%) occurs in the north. That means the north should be given more weight than the south when calculating a national elasticity. Average rural incomes increased steadily during 2012–2017 according to the official data. The average per capita income of the rural north is estimated to have been around 8,100 *yuan* in 2017, 44% higher than in 2012. The average per capita income of the rural south is estimated to have been around 9,100 *yuan*. Based on Table 5, the income elasticity in 2017 would have been around –0.3 in the north and around –3.2 in the south (calculated only based on incomes in 2017). The weighted average is –0.8. The estimated evolution of these elasticities over the period is shown in Fig. 5-1 (based on changes in average rural incomes alone).



(5-1) Income elasticity (5-2) Price elasticity

Fig. 5 Rural residential coal elasticities for 2012–2017.

Note: The weighting is based on rural coal consumption in 2012. Note that we do not have access to rural coal price data for 2013 onwards. These elasticities incorporate the effect of income growth but not of price changes.

Average expected price elasticities over 2012–2017 are provided in Fig. 5-2. As shown, our historical estimates suggest that the price elasticities of rural residential coal use are also likely to have become larger as a result of the observed income growth over the period. Over 2012–2016, China's coal prices declined by around 34%, before increasing by around 28% in 2017 (in nominal terms).[3] The rural residential price elasticity of coal demand values we have found in this study are useful for understanding the effects of such price swings on coal consumption by rural residents.

4. Comparing to previous studies

Many studies have estimated the price elasticity of demand for energy commodities, focusing on different time-response periods (short-run versus long-run), sectors, countries/regions, products, and the roles of other potential factors.

Prior scholars have not had a specific focus on coal demand among rural residences in China. Yu et al. (2014), for example, used the generalized least squares method to estimate the price and income elasticities of natural gas demand in urban China for 2006 to 2009. They found that the income elasticity is greater in the south than the north. Schulte and Heindl (2017) applied a quadratic expenditure system to estimate the own price elasticity for electricity used in space heating in Germany.

[3] This is based on the producer price index for the coal industry from NBS (2017, 2018).

As Ma and Stern (2016) summarized, different types of data (e.g. time series, cross-sectional, panel) and estimation approaches provide different estimates of elasticities. Their analysis concluded that the demand for coal in China is price inelastic, which differs from our finding for rural residences. Their research excludes residential consumption. Hang and Tu (2007) concluded that China's long-term price elasticity of demand for coal has changed significantly, evolving from around –0.3 before 1995 to around –1.6 after 1995. Our estimates focus on shorter-run responses.

There are several studies estimating the price elasticity of demand for coal at the provincial level in China. Zhang et al. (2013) found a positive elasticity for provinces located in the main coal regions, and a negative elasticity for provinces in the main consumption regions. Burke and Liao (2015) used provincial panel data to estimate the aggregate price elasticity of demand for coal, across all sectors. They obtained an inelastic result. In this paper, we find that rural residences have a more price-sensitive coal demand than that found by Burke and Liao. The difference is perhaps that households have greater flexibility to switch cooking or heating fuels, or adjust quantities. State-owned enterprises, on the other hand, may be less responsive to price, as discussed.

There are few studies specifically focusing on demand for coal in rural areas. Perez and Zepeda (2016) estimated a log-log model for rural Mexico. Their estimation of the income elasticity of rural coal use was –0.1. They concluded that residents turn to more convenient energy types when they have higher incomes. We found a much more sensitive negative response in the case of China. However, for provinces with low incomes, the elasticity indeed appears to be near zero.

5. Conclusions and implications

We estimated the aggregate price and income elasticities of coal demand for the household sector of rural China. In addition, we investigated the differences in elasticities between the north and south, and explored how elasticities tend to evolve with income. As far as we know, this is the first study to employ provincial-level data to explore this issue. We draw the following conclusions and implications.

(1) Household coal demand is sensitive to price in rural China, and there are differences between the north and south

Our econometric results show that on average the quantity of coal demanded by rural residences tends to decrease by around 1% when the real price increases by 1%. This is around unit elastic. This negative elasticity reflects the fact that households are likely to substitute to other fuels, or take energy conservation steps, when the price of coal increases. In absolute-value terms, the elasticity point estimates tend to be larger in the south, perhaps because rural households in the north have fewer substitution opportunities given their high reliance on coal-fired heating. Hence, price tools such as taxes may be proportionately more effective in reducing coal use in the south. However, coal consumption quantities in the north are far larger (Fig. 4), meaning that the total effect of a rural coal tax may well be larger in the north.

We find that the price elasticity of rural residential coal demand increases with income, equaling around –0.5 when annual per capita net income is 1,500 *yuan* and –1.8 at 8,000 *yuan*. A likely explanation is that as household incomes increase, they can more easily switch to alternative fuels such as electricity and gas if the coal price increases.

(2) Incorporating negative externalities into coal prices

One reform option would be to incorporate the external environmental pollution cost into the price of coal in rural areas through a Pigouvian tax (Burke, 2014). It would be possible to design such an intervention so that the tax revenue is returned to rural households, especially those with low incomes. If so, the policy could capitalize on both the negative price elasticity and the negative income elasticity that we have detected in our research. Implementing such a scheme would be challenging.

Mao et al. (2008) estimated that a tax representing the external cost of coal use would increase the coal price in China by about 23%. As mentioned, the rural household sector consumed around 82 million tons of coal in 2016 (NBS, 2017). Using a price elasticity of –1.0 (Table 2), complete internalization of the external costs would result in about a 19 million-ton reduction in annual coal consumption in rural China. Subsidies on technologies for clean energy, such as solar photovoltaics and batteries, are an alternative approach for reducing negative externalities from coal use, especially if taxing coal faces resistance or implementation challenges.

(3) Rising incomes can contribute to reducing coal use

We estimate that the income elasticity of rural residential coal demand in China is negative, consistent with coal being an inferior good. The net income level where the income elasticity descends below zero is around 2,300 *yuan* per person per year, equal to the national-average per capita income level for rural households in 2001 (NBS, 2002). Results with region dummy interactions provide evidence that, at the type of rural income levels prevailing in 2017, the negative income elasticity tends to be larger in the south than in the north.

Rural incomes have been rising since the end of our study period in 2012, a phenomenon that is likely to have placed downward pressure on rural residential coal use. At the same time, coal prices declined in China over 2012–2016 according to the NBS of China, which would have exerted an opposite effect. If incomes continue to increase steadily, the coal price does not experience a severe drop, and a coal tax scheme and/or alternative policies such as improvements in clean energy availability are implemented, residential coal use in rural China may be able to decrease substantially in the future. As a result, issues associated with air pollution from rural coal combustion may be able to be partly ameliorated.

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Appendix A.

Table A.1 Unit root test with Im, Pesaran and Shin (IPS)

Variable	Ln coal consumption$_{p,t}$	Ln coal price$_{p,t}$	Ln income$_{p,t}$	Temperature$_{p,t}$
Z-t-tilde-bar	-2.00	-3.03	-2.47	-5.15
p-value	0.023	0.001	0.007	0.000

Table A.2 Key variables correlation test

	Ln consumption$_{p,t}$	Ln price$_{p,t}$	Ln income$_{p,t}$	Temperature
Ln consumption$_{p,t}$	1.00			
Ln price$_{p,t}$	-0.47	1.00		
Ln income$_{p,t}$	-0.34	0.79	1.00	
Temperature	-0.50	0.12	0.08	1.00

We conduct residual analysis in Fig A.1.

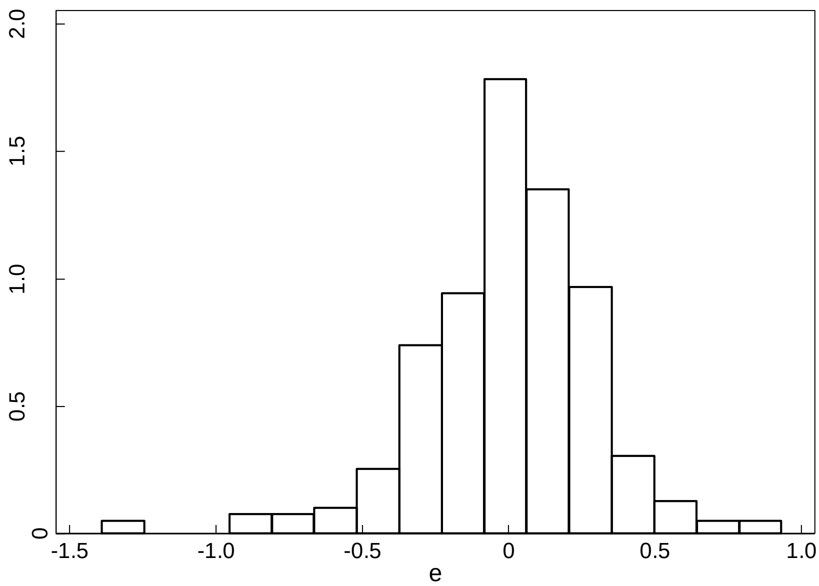

Fig A.1 Residual analysis based on our basic model