Household Energy Demand in Urban China: Accounting for Regional Prices and Rapid Income Change

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ABSTRACT

Understanding the rapidly rising demand for energy in China is essential to efforts to reduce the country's energy use and environmental damage. In response to rising incomes and changing prices and demographics, household use of various fuels, electricity and gasoline has changed dramatically in China. In this paper, we estimate both income and price elasticities for various energy types using Chinese urban household micro-data collected by National bureau of Statistics, by applying a two-stage budgeting AIDS model. We find that total energy is price and income inelastic for all income groups after accounting for demographic and regional effects. Our estimated electricity price elasticity ranges from −0.49 to −0.57, gas price elasticity ranges from −0.46 to −0.94, and gasoline price elasticity ranges from −0.85 to −0.94. Income elasticity for various energy types range from 0.57 to 0.94. Demand for coal is most price and income elastic among the poor, whereas gasoline demand is elastic for the rich.

Keywords: Household energy demand, China, Two-stage budgeting, LES-AIDS model

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1. INTRODUCTION

Due to its rapid urbanization and economic growth, China's energy consumption is rising at one of the fastest rates in the world—at nearly 8% per year over the 2000–2011 period—and residential energy consumption has grown even more rapidly. Specifically, household electricity and natural gas use rose at annual rates of 12.5% and 19.4%, respectively, over the last decade.[1] Although household energy consumption per capita remains low compared with developed countries, it is rapidly closing that gap. For instance, total energy use for cooking and heating has more than doubled during this period, from 123 kilograms standard coal equivalent (SCE) in 2000 to 278 kilograms in 2011.[2] Household gasoline consumption increased at an annual rate of 17% during the 2000–2010 period due to rapidly increasing motor vehicle use.[3] The International Energy Agency (IEA 2011) projects that China will dramatically increase its share of global oil consumption, and Chinese household energy consumption patterns are converging on those of the western

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1. Table 8.13 in NBS 2013.
2. Op. cit.
3. Table 4.8 in China Energy Statistical Yearbook 2013.

world. These changes will have a significant impact on China's total energy consumption, which, in turn, will have important implications for urban air quality.

Air pollution from past energy use has already led to serious damage. Utilizing conservative assumptions, the World Bank and SEPA (2007) has estimated that the health damage caused by air pollution alone amounted to 1.16% of GDP in 2003, in addition to another 0.26% worth of damage to agriculture and buildings. Higher numbers of household-owned vehicles are clearly a source of higher NOx emissions, even as reduced coal use by households has contributed to reduced levels of certain pollutants, such as particulate matter (PM). Nevertheless, most northern cities continue to rely heavily on coal for heating, which has maintained high PM levels. Current and projected levels of PM and ozone pose a severe public health challenge. Successful strategies to reduce pollution from household energy use require a solid understanding of the factors that drive residential energy demand, i.e., how households respond to changes in income, prices, technology and urban structure, given that demographic profiles are also changing. Nonetheless, given the importance of this topic, research on urban household energy consumption using Chinese microdata are surprisingly scarce. Most recent studies of Chinese household energy consumption have concentrated on modeling aggregate demand because individual household data are generally unavailable (Shonali Pachauri and Leiwen Jiang, 2008; Li et al., 2011; Zhen et al., 2011). Since preferences for energy differ based on household characteristics, including age, employment status, household size, and stock of durables, energy consumption behavior is not estimated particularly well with aggregate data (Baker and Blundell, 1991).

Another group of papers on Chinese household energy demand has studied the demand for particular types of energy use based on household data using single equation models (Xu, 2012; Zheng et al., 2011; Murata et al., 2008). Such models impose strong separability restrictions and are thus unable to estimate the cross-price effects between different energy commodities (Labandeira et al., 2006). Current empirical research on Chinese household energy demand thus does not allow for accurate and comprehensive prediction of consumer responses to government policies.

One of the more sophisticated methods of modeling household energy demand consists of multiple equation systems that include all energy types and also allow for individual households to have different energy consumption patterns based on birth and education cohort, employment status, household size, stock of durables, etc. The availability of a long time-series of household data enables us to recover more precise price and income responses that take into account these differences in household characteristics. Jorgenson, Slesnick and Stoker (1988) estimated residential energy demand for electricity, natural gas, fuel oil, and gasoline at the household level, while Baker, Blundell, and Micklewright (1989) and Baker and Blundell (1991) estimated household energy demand for electricity, gas, and other energy sources that accounted for cross-price effects. More recent papers, such as Labandeira and Labeaga (1999), Tiezzi (2005), Labandeira et al. (2006), and Gundimeda and Köhlin (2008), have also estimated household demand for different types of energy using multiple equation modeling.

The main objective of this paper is to fill a gap in the literature and provide a better estimate of the income and price elasticities of household demand for various types of energy in urban China, while accounting for the vast differences in regional prices and incomes using microdata. Most of the current studies estimate China's energy demand using more macro-level price and quantity data such as provincial level data, and are thus unable to control for household characteristics. Although more advanced methods such as quasi-experiments or experiments have been applied on energy demand elasticities in developed countries, there are no such studies published in China yet partly due to the data availability issues. Considering big differences upon institutions and consumer patterns between China and other developed countries, directly referencing these existing elasticities from developed countries would be quite misleading, even with the latter using more advanced state-of-the-art experimental or quasi-experimental methods. China is experiencing big changes, in terms of household demographics, income level as well as behavior changes, such rapid transition has not been experienced by other countries at such as speed. We might expect price elasticities of demand on energy maybe higher in China, considering rising energy prices may co-change with the urban infrastructure shift, while most recent studies in western countries often locked in certain infrastructure environment. So our paper fills the gap in the literature and help us better understand the underlying factors determining household energy demand in China.

It is well established that household demand for energy services depends on appliance and housing stocks (McFadden et al., 1977; Hausman et al., 1979). Dennerlein and Flaig (1987), Baker and Blundell (1991), Zweifel et al. (1997), Alberini et al. (2011), and Fell et al. (2012) introduce appliance dummies to control for the effects of durables on energy consumption, whereas Garbacz (1984) and Tiwari (2000) define an appliance stock index . Dwelling characteristics have also been shown to affect price and income elasticities (Baker and Blundell, 1991; Reiss and White, 2005; Labandeira et al., 2006). Our household data allow us to consider conditional demand in greater detail than previous research on Chinese demand; in particular, the detailed information on the stocks of household appliances and housing characteristics.

It is essential to have accurate measurements of household income and prices to estimate elasticities. The quality and coverage of the consumption data in China have been widely discussed and debated, including the lack of estimates for owner-occupied housing (e.g., Benjamin, Brandt, Giles and Wang 2008). A secondary objective of this paper is to develop a more complete measure of housing expenditures (and related imputed incomes) and prices.

We use a two-stage budgeting approach in which total expenditures are allocated to energy and nonenergy consumption in the first stage. We must thus construct prices for the energy and nonenergy bundles. Since prices vary substantially across provinces in China, we follow Brandt and Holz (2006) in constructing provincial energy and nonenergy price indices, in addition to the values of the consumption baskets in the base year. We are able to estimate price and income elasticities more precisely with such wide spatial price differences.

Past research has indicated that energy preferences shift with household income (West and Williams, 2004; Gundimeda and Köhlin, 2008), with the gender of the head of the household (Somani, 2013), the education, employment status, age and birth cohort of the head of the household (Baker and Blundell, 1991; Labandeira et al., 2006), and the age of children (Labandeira et al., 2006). To control for this observable heterogeneity, we divide households into three groups based on expenditure levels (low, middle and high income), and we include dummies for the gender, education level, birth cohort and employment status of the head of the household, in addition to age-group dummies for children.

Our data set—the China Urban Household Survey (CUHS)—was collected by the National Bureau of Statistics (NBS) over the 2002–2009 period and included nearly 15,000 households each year with detailed data on energy consumption. The CUHS is used by the NBS to compute both the CPI and the consumption component in the National Accounts.

The remainder of this paper is structured as follows. Section 2 begins with the two-stage budgeting model of household energy demand, specifying all the household characteristics discussed above. In section 3 we describe the data, the construction of the spatial price indices, the appliance stocks, and imputation of owner-occupied housing, and we discuss the household demographic characteristics we utilize. In section 4 we present the empirical results, and we conclude the paper in section 5 by summarizing our main findings and the corresponding policy implications.

2. MODEL OF CONSUMER BEHAVIOR

2.1. Two-stage Budgeting

The two-stage budgeting approach dates to Gorman (1959, 1971), and Jorgenson and Slesnick (1988) and Baker, Blundell and Mickelwright (1989) are some of the earlier papers to apply the method to household energy demand. In recent applications, households are assumed to behave as individual consuming units and to allocate their expenditures in two stages to maximize a utility function, which is conditional on the stock of durables and on leisure choices. In the first stage, total expenditures are allocated to a basket of energy commodities and other goods. In the second stage, total energy expenditures are allocated to different types of energy. Gundimeda and Köhlin (2008) represents a more recent application of two-stage budgeting using Indian microdata.[4] We follow this literature by allowing households to allocate total nondurable expenditures between a basket of energy commodities and a basket of nonenergy commodities in the first stage, and total energy expenditures are allocated in the second stage to four types of commercial energy, i.e., coal, gas, electricity and gasoline.

2.1.1 First-stage allocation

In the first stage, we allocate total expenditures to an energy bundle and a nonenergy bundle using a linear expenditure system (Fan, Wailes and Cramer, 1995 and Labandeira et al., 2006) in which the value of the demand of household *k* in province *pro* in period *t* for bundle *I* is the following:

$$p_{I,pro,t}q_{Ikt} = \gamma_I p_{I,pro,t} + \beta_I\Big(y_{kt} - \sum_J \gamma_J p_{J,pro,t}\Big) \quad I,J = \{energy,\ non\text{-}energy\} \tag{1}$$

$p_{J,pro,t}q_{Jkt}$ represents the expenditures allocated to bundle *J*, $p_{I,pro,t}$ is the price index of *I*, y_{kt} represents total household expenditures and γ_J is the minimum required quantity of *J*, which may be interpreted as the subsistence consumption. Households then allocate the remaining non-subsistence expenditures $y_{kt} - \sum_J \gamma_J p_{J,pro,t}$ (the supernumerary expenditures) between energy and nonenergy commodities in fixed proportions β_I, where $\sum \beta_I = 1$. Hence, apart from the subsistence expenditures, total consumption is divided into fixed shares between energy and nonenergy commodities in the first stage.

2.1.2. Second-stage allocation

In the second stage, households' energy expenditures (y_{ekt}) are allocated to four types of energy, i.e., electricity, gas, coal, and gasoline.[5] "Gas" is the aggregate of coal gas, natural gas,

4. In Gundimeda and Köhlin (2008), the first stage contains the share of energy in total expenditures as a function of demographic characteristics and total expenditures. In the second stage, they estimate an AIDS model for wood, kerosene, LPG and electricity. Fan, Wailes and Cramer (1995) use a linear expenditure system for first-stage and an AIDS model for second-stage demand for individual food items.

5. Most apartments in north China have central heating, and a fixed fee is charged based on the size of the house. We do not estimate the demand for heating, and we aggregate these fees with the nonenergy expenditures (following Labandeira et al. 2006). We include central heating as a dummy variable.

piped petroleum gas and LPG in tanks. "Gasoline" includes both gasoline and diesel. Let y_{ekt} denote the total energy expenditures of household k, and the share of the i^{th} type of energy in y_{ekt} is

$$w_{ikt} = p_{ikt}x_{ikt}/y_{ekt} \quad k = 1,\ldots,K;\ i = electricity,\ gas,\ coal,\ gasoline$$

where p_{ikt} is the price of the i^{th} type of energy that household k faces in period t, and x_{ikt} is the quantity of energy.

We assume that the k^{th} household allocates this energy expenditure according to an AIDS expenditure (i.e., cost) function:

$$\log C_{kt}(P_{kt},u_{kt}) = (1 - u_{kt})\log[a(P_{kt})] + u_{kt}\log[b(P_{kt})] \tag{2}$$

where u_{kt} is the utility, P_{kt} is a vector of the individual energy prices that household k faces, and $a(P_{kt})$ and $b(P_{kt})$ are defined as follows:

$$\log a(P_{kt}) = \alpha_0 + \sum_i \alpha_i \log p_{ikt} + \frac{1}{2}\sum_i \sum_j \gamma_{ij} \log p_{ikt} \log p_{jkt} \tag{3}$$

$$\log b(P_{kt}) = \log a(P_{kt}) + \beta_0 \prod_i p_{ikt}^{\beta_i} \tag{4}$$

i,j = electricity, coal, gas, gasoline; $k = 1,\ldots,K$

Thus, the expenditure function, written out in full, is:

$$\log C_{kt}(P_{kt},u_{kt}) = \alpha_0 + \sum_i \alpha_i \log p_{ikt} + \frac{1}{2}\sum_i \sum_j \gamma_{ij} \log p_{ikt} \log p_{jkt} + u_{kt}\beta_0 \prod_i p_{ikt}^{\beta_i} \tag{5}$$

where the coefficients α_i are allowed to differ by demographic characteristics. We assume $\alpha_i = \omega_{i0} + \sum_l \omega_{il} d_{lkt}$, where the dummy variable d_{lkt} represents the l^{th} characteristic, and ω_{i0} and ω_{il} are parameters to be estimated.

The expenditure shares, derived using Shephard's Lemma, are:

$$w_{ikt} = \omega_{i0} + \sum_l \omega_{il} d_{lkt} + \sum_j \gamma_{ij} \log p_{jkt} + \beta_i \log \frac{y_{ekt}}{P_{kt}} \tag{6}$$

where ω_{il}, γ_{ij}, β_i are parameters.[6] The household price index P_{kt} is defined as:

$$\log P_{kt} = \alpha_0 + \sum_i \alpha_i \log p_{ikt} + \frac{1}{2}\sum_i \sum_j \gamma_{ij} \log p_{ikt} \log p_{jkt} \tag{7}$$

6. As discussed in Baker et al. (1989), symmetry and homogeneity restrictions must be imposed on the parameters. The restrictions are: $\sum_i \alpha_i = 1$, $\sum_i \beta_i = 0$, $\gamma_{ij} = \gamma_{ji}$, $\sum_j \gamma_{ij} = 0$, $\sum_i \omega_{i0} = 1$, $\sum_i \omega_{ik} = 0$

To begin the estimating procedure for (6), an initial value is required for the household price, P_{kt}, because (7) depends on the unknown parameters, and we follow Deaton and Muellbauer (1980) in using the linear price index developed by Stone (1954), defined by:

$$\log P_{kt} = \sum_i \bar{w}_{it} \log p_{ikt} \tag{8}$$

where $\bar{w}_{it}$ represents the expenditure shares averaged over the entire sample.

Thus, in the first step, we use (8) to estimate the parameters in (6) using the seemingly unrelated regression (SUR) technique with homogeneity and symmetry restrictions imposed. Next, we compute a new price index for P_{kt} using the estimated parameters and (7). Then, the demand system (6) is re-estimated using the new price index. The procedure is repeated until the parameters converge.

2.2. Estimation Method

In the first stage allocation, the linear expenditure system is estimated using nonlinear least squares. We have just described the iterative SUR procedure for the second stage. There is a complication, however, because few middle- and high-income households consume coal, and very few low-income households use gasoline. To avoid problems related to minimal shares, we assume that low-income households consume only electricity, coal and gas, and assume that middle- and high-income households consume only electricity, gas and gasoline.

Even using these smaller sets of energy choices, some households have zero expenditures on certain energy types. In other words, there are two decisions for each household: whether to consume a particular energy type and how much of it to consume. To correct for selection bias, we first estimate a probit function for choosing energy i:

$$P(x_{ikt} > 0 \,|\, p_{1kt}, \ldots, p_{4kt}, y_{kt}, d^*_{1kt}, \ldots, d^*_{mkt}) = \Phi(x_{kt} \cdot \upsilon) \tag{9}$$

where Φ is the cumulative distribution function (CDF) of the standard normal distribution, and the selection function depends on prices, total energy expenditures and demographic characteristics.

From the probit regression, we obtain the inverse Mills ratio for type i energy, $\hat{\lambda}_{ikt} \equiv \lambda(x_{ikt} \cdot \hat{\upsilon})$, where ϕ is the normal density function and $\lambda_{ikt}(\cdot) \equiv \dfrac{\phi_{ikt}(\cdot)}{\Phi_{ikt}(\cdot)}$.

When household k decides to consume energy type i, it will also determine how much to spend on it. To correct for sample selectivity, following Heien and Wessells (1990), many studies add $\hat{\lambda}_{ikt}$ to the second step and estimate the following:

$$w_{ikt} = \omega_{i0} + \sum_l \omega_{il} d_{lkt} + \sum_j \gamma_{ij} \log p_{jkt} + \beta_i \log \frac{y_{ekt}}{P_{kt}} + \xi_i \hat{\lambda}_{ikt} + \varepsilon_{ikt} \tag{10}$$

Estimating (10) using the entire sample, however, is biased when there is a large number of censored observations, as noted by Shonkwiler and Yen (1999) (and also discussed in the Appendix of West and Williams, 2004). OLS regressions that use only the positive shares are also inconsistent. To avoid this inconsistency, we use the equation introduced by Shonkwiler and Yen (1999) for censored seemingly unrelated regressions (see also Yen et al. (2002) and Akbay et al. (2007)):

$$w_{ikt} = \hat{\Phi}_{ikt} \cdot \left(\omega_{i0} + \sum_l \omega_{il} d_{lkt} + \sum_j \gamma_{ij} \log p_{jkt} + \beta_i \log \frac{y_{ekt}}{P_{kt}} \right) + \xi_i \hat{\varphi}_{ikt} + u_{ikt} \quad (11)$$

where Φ_{ikt} is the normal CDF of household k for individual energy i, and ϕ_{ikt} is the normal density function. Since the maximum likelihood (ML) probit estimators are consistent, the SUR method for equation (11) produces consistent estimates in the second stage.

Formulas for the price and income elasticities are given by Blanciforti, Green, and King (1986), Yen et al. (2002), Yen et al. (2004) and Akbay et al. (2007).[7]

3. DATA

3.1. Data Sources and Issues

We use an annual micro-level data set from the China Urban Household Survey (CUHS) collected by the National Bureau of Statistics for 2002–2009. The CUHS uses a stratified multistage method to select its samples. We have a sample of about 15,000 households per year covering nine provinces in eastern, central and western China: Beijing, Liaoning, Zhejiang, Anhui, Hubei, Guangdong, Sichuan, Shaanxi and Gansu.[8] The sampled households are required to keep a detailed record of their incomes and expenditures every day. The data also provide detailed information regarding demographic characteristics, housing and household expenditures, and—importantly—detailed value and quantity data on individual types of energy.

There are some extreme values for expenditures, individual energy consumption and implied prices. We censor total consumption for each commodity type that is more than two times the 99th percentile. For those households whose head is unidentifiable, we choose the middle-aged male with the highest income as the head of the household. After data cleaning and treatment of outliers, we are left with 119,780 observations for the 2002–2009 period.

The survey gives quantities and values for the purchases of coal, gas, electricity and gasoline. One can impute unit values of individual energy from these data. However, some households do not use certain types of energy, and for these we use the average price in the city where they are located. If there is no observation for a city using a particular type of energy, we assume that households in that city face the provincial average price.

3.2. Income Groups and Imputations

Given the large differences observed in consumption patterns, many studies estimate the demand functions separately for the rich and the poor. We also classified the households into three

7. The conditional (on the 1st stage) price elasticities are as follows:

$$\eta_{ij,I} = \hat{\Phi}_{ikt} \cdot \left(\frac{\gamma_{ij,I}}{E(w_{i,I})} - \beta_{i,I}\frac{\alpha_{i,I}}{E(w_{i,I})} - \frac{\beta_{i,I}}{E(w_{i,I})}\sum_{j,I}\gamma_{ij,I}\log p_{j,I}\right)$$

$$\eta_{ii} = -1 + \hat{\Phi}_{ikt} \cdot \left(\frac{\gamma_{ii,I}}{E(w_{i,I})} - \beta_{i,I}\frac{\alpha_{i,I}}{E(w_{i,I})} - \frac{\beta_{i,I}}{E(w_{i,I})}\sum_{i,I}\gamma_{ii,I}\log p_{i,I}\right)$$

while the conditional income elasticity is expressed as follows: $e_{ie} = 1 + \hat{\Phi}_{ikt} \cdot \frac{\beta_{i,I}}{w_{i,I}}$, the unconditional income and price elasticities are: $e_{iY} = e_{eY} \cdot e_{ie}$ and $\eta_{ij} = \eta_{ij,I} + e_{ie} w_{j,I}(1 + \eta_{II})$

8. The CUHS data for these nine provinces were provided by China Data Center, Tsinghua University.

groups: low, middle and high income. We use household annual expenditures as a proxy for lifetime income and define the low-income group as households in the lowest 20% of the expenditure distribution. The next 60% of households are defined as the middle-income group and the highest 20% are in the high-income group.[9]

China's consumption data—particularly regarding data quality and coverage—have been widely discussed and debated during the past decade (e.g., Benjamin, Brandt, Giles and Wang 2008). The biggest issue is housing consumption, which has changed dramatically. In the early 1990s, urban residents rented from the public sector[10] at low rents, but the public sector has been selling housing to public employees since 1994, and the State Council required all public housing and that of state-owned enterprises to be sold. By 2009, more than 80% of urban Chinese households owned their residences, and housing prices had thus changed significantly. According to Xu et al. (2012), the share of housing costs out of total household consumption by 2010 was between 23.6% and 40.9% in the four large cities (Beijing, Shanghai, Guangzhou, Shenzhen).[11] However, this major consumption item is not explicitly noted in the National Accounts, as reported in the China Statistical Yearbook. Such owner-occupier expenditures are not included in the CUHS and its housing expenses are thus severely understated. The value of the residence—and thus the imputed rent—is strongly correlated with the household's durable goods and assets. Underestimating owner-occupied housing would overestimate high-income households' elasticities.

Imputing owner-occupied housing rents is difficult in China because of the lack of survey data. Liu (2001) and Zhao et al. (1999) estimated a 9% housing rent-price ratio in 2001 for residences in Shanghai. This ratio was too high to be used in other cities in China, even in the early years. Chen (2012) estimated the housing rent-price ratio in Beijing, Shanghai, Guangzhou and Shenzhen for the 1991–2010 period and found declining rent-price ratios as a trend. Most recently, the ratio was approximately 3% in the sample of those four cities. However, even with estimates of national housing prices, we still could not use these ratios directly. First, fewer than 20% of the households in those cities rented during that period. Second, similar studies were not conducted for other types of cities. Housing price inflation is much higher in the largest cities and they tend to have lower rent-price ratios.

To gain a more complete measure of household expenditures, we impute the owner-occupied housing rental equivalent using current housing values reported in the CUHS. Given the above results, and assuming that Chen's (2012) 3% ratio for the largest cities underestimates the national rent-price ratio, we take a simple approach and assume a 4% national average rent-price ratio. That is, our imputation of the annual rentals of owner-occupied housing is the reported housing value multiplied by 4%.

9. Our data suggest people grouped in the middle income group have similar characteristics and expenditure patterns, so we group more samples in the middle income groups. We also tried more groups and our results suggest these middle income group shows very similar coefficients regardless as a group or more sub-groups.

10. In the urban survey, the public sector includes both state-owned enterprises and institutions, and collective-owned enterprises and institutions.

11. In the SNA, household consumption consists of two parts: market rent and the rental equivalent of owner-occupied housing (Xu et al., 2012). Market rent is the rental price that households actually pay in a market transaction. Owner-occupied housing rent is an imputed value that should ideally be based on equivalent rental units. In the Chinese National Accounts, the imputation is made based only on the depreciation of the structure's construction cost, with an assumed depreciation rate of 2% in the most recent Accounts.

3.3. Spatial Prices

3.3.1. Spatial prices for the first-stage estimation

Following Brandt and Holz (2006), we first calculate the values of the energy and nonenergy baskets for each province in 2002, the base year. Using the provincial urban CPI, we then calculate the provincial energy and nonenergy price indices for the 2003–2009 period. In this paper, energy consumption includes coal, electricity, gas and fuel for motor vehicles. Nonenergy consumption includes food and other consumable goods, housing rents, and services. The data sources for prices are summarized in Table A1.

Provincial energy price indices are constructed using the composite price indices of coal, gas and electricity published in the China Urban Life and Price Yearbook (CULPY) and provincial gasoline prices from International Petroleum Economics Monthly (IPE). The CULPY also publishes energy consumption shares by detailed energy types. Individual energy shares are used as weights to construct the energy basket price indices, and the nonenergy price indices can thus be calculated.[12] The Beijing price in 2002 is used to normalize the panel of provincial prices.

3.3.2. Spatial prices of the second-stage estimation

To estimate individual price and income elasticities, we divide energy consumption into three categories for each income group as discussed above. The low-income group consumes electricity, gas and coal, while the middle- and high-income groups consume electricity, a gas-coal aggregate, and gasoline.

For the detailed energy types, we do not have to rely on provincial averages; following Gundimeda and Köhlin (2008), we impute unit prices using the quantity and value data for electricity and coal use in the household surveys.[13] As shown in Table 1, there is enough price variations in our data. For instance, the mean electricity price is about 0.55 Yuan/KWh, with a standard deviation (SD) of about 0.10 Yuan/KWh. The mean coal is about 0.66 Yuan/Kg, with a standard deviation of 0.3; for gasoline price, the mean is about 5 Yuan/litre, and a standard deviation of 2.3.[14]

The CUHS only began reporting quantities and values for gases and transportation fuels in 2008. For transportation energy, there are expenditures for gasoline, diesel and electrical charging. More than 99% of household transportation fuel expenditures are for gasoline, and we simply assume that the transportation energy price is the gasoline price. Before 2008, only expenditures for transportation fuel are available, and for prices, we must use the annual provincial gasoline prices from IPE for all households in a given province. Using these provincial gasoline prices, we

12. The provincial price of energy (relative to Beijing) is calculated as the Tornqvist index of the four energy types: $\ln P^{E}_{pro,bj} = \frac{1}{2}\sum_{l=1}^{4}(w_{l,pro} + w_{l,bj})\ln\left(\frac{P^{l}_{pro}}{P^{l}_{bj}}\right)$. The price of the nonenergy basket is calculated as a residual from the provincial CPI aggregate: $\ln P^{CPI}_{pro,bj} = \frac{1}{2}\sum_{l\in energy,\, nonenergy}(w_{l,pro} + w_{l,bj})\ln\left(\frac{P^{l}_{pro}}{P^{l}_{bj}}\right)$.

13. Unit price imputed from household expenditures and quantities may sometimes have measurement errors, but such data provide more variations then using provincial price averages.

14. Even within each province there are also enough price variations across individual cities. For instance for electricity, the average standard deviation within each province ranges from 0.03 yuan/KWh to 0.11 yuan/KWh.

construct provincial transportation fuel inflation rates. These provincial inflation rates are then combined with county-level gasoline prices that we compute from the CUHS in 2008, giving us a series of county-level gasoline prices for 2002–2007.

There are four types of cooking gas in our data: coal gas, piped petroleum gas, natural gas, and bottled LPG. The survey reports expenditures on and quantities of these gases since 2008, and we can calculate unit prices.[15] For 2002–2007, the survey only reports bottled LPG and "gas", and there are no details for different types of gases. We turn to prices collected by the National Development and Reform Commission[16] to impute gas prices. We first identify the counties, or county-level cities, that did not change their type of piped gas. We can thus infer the types of gas that the households in those cities or counties used before 2008. We are then able to use the unit value of a given type of gas and convert the units to coal gas-equivalents. For the middle- and high-income groups, we only identify a single gas-coal group and compute a group price index.

The Chinese government has different policies for different types of energy. For coal and gas, the pricing authority varies greatly across counties and districts, and local governments can determine their own energy supply investments and subsidies. In the CUHS data, we indeed observe rather large variations across regions and years. For electricity and gasoline, the central government has overwhelming pricing authority—and local governments have limited authority—although there are some variations across provinces. As a result, electricity and gasoline prices vary less compared with coal prices across regions and over time. To eliminate the time-series and cross-sectional fixed effects, we use year dummies, provincial dummies and the interaction of the year and provincial dummies in our regression.

Some counties price electricity in blocks, with rising prices for higher consumption, which complicates the calculation of the marginal price. This is not a serious issue here, firstly, this block pricing was introduced in only two of our provinces in this sample period. Secondly, in one of these provinces, Zhejiang, 97% of the households in the sample are consuming electricity in the first block.

Table 1 gives some summary statistics for the three income groups and shows how energy consumption patterns differ greatly across groups; for example, the richer the household, the smaller the expenditure shares of coal and gas. Gasoline consumption is 20.6% of total energy consumption for rich urban households, but these households consume little coal. Electricity plays the most important role in urban household energy, and electricity prices are nearly the same across income groups and vary little over the sample period. However, the poorer households face somewhat lower coal prices in our sample, most likely because they are located in or near coal-producing regions. Gasoline prices are slightly cheaper for the higher income groups on average because of lower transportation costs to the major urban centers in which they are disproportionately located.

The household characteristics that we have chosen to include in our model are household size, presence and age of children, and the age, gender and employment status of the head of the household. Employment status distinguishes among those who work in the public sector and those

15. We use heat values to convert the gas prices to a coal-gas equivalent price for household k for 2008–2009 as follows:

$$p_{kt}^{gas} = p_{kt}^{coal\ gas} w_{kt}^{coal\ gasy} + \frac{67}{217} p_{kt}^{LPG} w_{kt}^{LPG} + \frac{67}{160} p_{kt}^{natural\ gas} w_{kt}^{natural\ gas} + \frac{67}{486} p_{kt}^{petrolgas} w_{kt}^{petrolgas}$$

$p_{kt}^{coal\ gas}$, p_{kt}^{LPG}, $p_{k,t}^{natural\ gas}$ and $p_{k,t}^{petrolgas}$ are the household unit prices of coal gas, LPG, natural gas and piped petroleum gas, respectively, and the w's are the corresponding shares within the gas basket. The conversion factors are from the Chinese Energy Statistical Yearbook 2011, Appendix IV.

16. These data are surveyed by the National Development and Reform Commission every ten days.

Table 1: Summary Statistics by Expenditure Group

Expenditure group Variables	Low Mean	Low SD.	Middle Mean	Middle SD.	High Mean	High SD.
Expenditure (Beijing 2002 Yuan)	4,154	1,108	9,034	2,963	21,546	9,018
Shear of energy in total expenditure (%)	0.07	0.04	0.06	0.03	0.05	0.04
Price electricity (Yuan/kwh)	0.55	0.10	0.55	0.09	0.56	0.09
Price coal (Yuan/kg)	0.66	0.39	0.67	0.33	0.69	0.30
Price gas (Yuan/cubic meter)	2.24	2.14	2.25	1.69	2.35	1.76
Price gasoline (Yuan/litre)	5.51	2.35	5.34	2.28	5.09	2.30
Electricity share of energy (%)	55.0	20.9	58.3	20.5	53.5	25.3
Coal share of energy (%)	9.4	18.7	3.2	10.6	0.8	5.3
Gas share of energy (%)	32.5	20.6	31.7	18.4	25.1	18.6
Gasoline share of energy (%)	3.0	10.1	6.8	17.1	20.6	30.3
Number of obs.	23,800		71,265		23,631	

Note: the prices of individual energy have been deflated using provincial CPI.

Table 2: Sample Distribution by Demographic Characteristics and Expenditure Group

		Expenditure group: Low	Medium	High
Household size (number of members)		3.33	2.87	2.60
Child (%)	No child	42.00	56.26	67.17
	Child: 0–12	36.69	26.14	19.62
	Child: 13–18	23.52	18.39	13.64
Age of household head (%)	Age of head 0–34	9.33	9.31	11.28
	Age of head 35–55	63.24	61.64	57.49
	Age of head 56 +	27.43	29.05	31.23
Gender of household head (%)	male	74.54	70.27	64.64
	female	25.46	29.73	35.36
Occupation of household head (%)	public	38.73	49.14	48.15
	non-public	61.27	50.86	51.85

who do not. Different income groups have different demographic compositions; for example, the low-income group has larger average household sizes and is more likely to have children, particularly younger children. For poorer households, the household heads are younger, less often female and less likely to work in the public sector. In Table 2, we give the sample distribution by these demographic categories and income groups. To avoid collinearity in the 2nd step of the Heckman two-step procedure, we exclude two demographic categories from (11) that are included in (9): gender of household head and age of children. Gender is significant for the low income probit and age of children is also significant for the middle and high income probits, however, the gender of the head is least likely to affect their expenditure shares compared to other characteristics. The presence of a child is important, but whether the child is less than 12, or is 12–18, has a small impact on energy expenditure shares.

Given the structure of compensation, we distinguish households by the employment status of the head. Most workers in state-owned enterprises (SOEs) or collective-owned enterprises (COEs) live in downtown areas, in which there is more convenient access to high-quality energy

Table 3: Individual Energy Prices and Dining Out by Employment Status

Employment status of household head	Prices household faces (Yuan) electricity	gas	coal	Share of dining out (%)
Public	0.546	2.227	0.627	22.0
Non-public	0.555	2.312	0.701	16.6

Table 4: Estimates of LES model of Total Energy Expenditures (First Stage)

VARIABLES	Expenditure of total energy		
Expenditure group	Low	Middle	High
γ_e	144.9***	274.8***	505.5***
	(5.129)	(4.633)	(15.07)
γ_{ne}	1755***	3925***	7118***
	(342.5)	(290.0)	(895.9)
β_I	0.0543***	0.0412***	0.0424***
	(0.0010)	(0.0004)	(0.0006)
Observations	23,958	71,871	23,951
R-squared	0.778	0.718	0.643

Standard errors in parentheses: *** $p<0.01$, ** $p<0.05$, * $p<0.1$
Note: provincial dummies, year dummies and the interactions are not reported.

at lower prices. The public sectors also subsidize or provide food for their workers, which allows them to spend less on food at home. In Table 3, we give the average prices faced by the two employment groups as well as shares of total expenditures devoted to eating out of the home. We find that households in which the head works in the public sector have access to cheaper energy and have a higher share of dining out expenditures.

We include provincial dummies to capture the differences across provinces with respect to local culture, resource endowment and climatic conditions. Beijing, Zhejiang and Guangdong are the richer provinces, whereas Liaoning, Shaanxi and Gansu are poorer.

4. EMPIRICAL RESULTS

4.1. Price and Expenditure Elasticities of Total Energy Consumption

The results of estimating the first-stage equation (1) are given in Table 4. All the parameters of the first-stage regression are significant at the 1% level. Recall that we only have provincial prices—and not household-specific prices—for the energy and nonenergy baskets.

Table 5 gives the expenditure and price elasticities of the energy bundle by income group, which are all significant at the 1% level. Energy is a necessity for all groups; the expenditure elasticities range from 0.712 for the poor to 0.852 for the rich.

The price elasticities are significant at the 1% level and range from −0.367 to −0.180. The high-income group is less price elastic than the other two groups.

Table 5: Estimated Elasticities for Energy in the First Stage LES Model

	Low	Middle	High
price elasticity	−0.367***	−0.358***	−0.180***
std. dev.	(0.001)	(0.000)	(0.000)
expenditure elasticity	0.712***	0.713***	0.852***
std. dev.	(0.013)	(0.007)	(0.011)
Obs.	23, 958	71,871	23,951

Table 6: Probit Estimate for Coal and Gasoline Selection

		Choice of Gasoline	
VARIABLES	Choice of Coal Low	Middle	High
Price electricity	0.700***	0.273***	0.495***
	(0.0900)	(0.0586)	(0.129)
Price gas (low income) or price coal & gas (middle, high)	0.335***	0.288***	0.298***
	(0.0204)	(0.0143)	(0.0210)
Price coal (low income) or price gasoline (middle, high)	−1.613***	−4.352***	−0.532***
	(0.0387)	(0.116)	(0.109)
Log of energy expenditure	0.0723***	0.452***	0.784***
	(0.0161)	(0.0117)	(0.0163)
Public sector: household head	−0.0806***	0.188***	0.0614***
	(0.0213)	(0.0101)	(0.0219)
Household size	0.0948***	0.110***	0.256***
	(0.0126)	(0.0142)	(0.0183)
Has child: age < 12	0.0253	0.103***	0.196***
	(0.0240)	(0.0212)	(0.0364)
Has child: 12 < = age < 18	0.00111	0.000253	0.0647*
	(0.0247)	(0.0201)	(0.0347)
Gender of household head: Female	−0.0702***	−0.0222	−0.0383*
	(0.0222)	(0.0149)	(0.0229)
Household head's age 35–54	−0.0154	−0.121***	−0.128**
	(0.0355)	(0.0337)	(0.0594)
Household head's age 55 +	0.218***	−0.0364	−0.152*
	(0.0422)	(0.0499)	(0.0804)
Durable dummies	Y	Y	Y
Constant	−0.111	−4.192***	−6.125***
	(0.289)	(0.125)	(0.164)
Observations	23,782	69,024	22,914

Standard errors in parentheses, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$
Note: provincial dummies, year dummies, the interactions, age and education dummies are not reported. We define 11 age cohorts and 3 education groups for the household head. The age cohorts are: born before 1930, 1930–1934, 1934–1939, 1940–1944, 1945–1949, 1950–1954, 1955–1959, 1960–1964, 1965–1969, 1970–1974, and 1975 + . The education groups are: primary school, middle school, and college. There are similar dummies for the spouse.

4.2. Probit Estimation of Adopting Particular Energy Types

In Tables 6 and 7, we present the probit estimates for equation (9). We do not have to consider the electricity choice because nearly all households in urban China have access to, and

Table 7: Probit Estimate for Gas Selection

VARIABLES	Gas	Gas & coal	
Income group	Low	Medium	High
Price electricity	0.904***	0.771***	0.589***
	(0.0951)	(0.0652)	(0.164)
Price gas (low income) or price coal & gas (medium, high)	0.115***	−0.234***	−0.305***
	(0.0277)	(0.0237)	(0.0412)
Price coal (low income) or price gasoline (medium, high)	0.849***	0.363***	0.222
	(0.0423)	(0.135)	(0.255)
Log of energy expenditure	0.633***	0.395***	0.222***
	(0.0192)	(0.0130)	(0.0178)
Household size	0.0320	0.163***	−0.156***
	(0.0254)	(0.0180)	(0.0354)
Public sector: household head	0.134***	−0.119***	0.104***
	(0.0153)	(0.0224)	(0.0316)
Has child: age < 12	0.0149	0.00677	−0.0975*
	(0.0291)	(0.0341)	(0.0582)
Has child: 12 < = age < 18	0.0216	0.0122	0.0108
	(0.0297)	(0.0318)	(0.0567)
Gender of household head: Female	0.0899***	0.0283	0.0520
	(0.0270)	(0.0225)	(0.0348)
Household head's age 35–54	0.0152	0.0370	0.00175
	(0.0414)	(0.0508)	(0.0891)
Household head's age 55 +	−0.0904*	0.105	−0.0683
	(0.0497)	(0.0760)	(0.126)
Durable dummies	Y	Y	Y
Constant	−2.394***	−0.795***	−0.175
	(0.463)	(0.177)	(0.206)
Observations	23,503	69,024	22,814

Standard errors in parentheses, *** $p<0.01$, ** $p<0.05$, * $p<0.1$
Note: provincial dummies, year dummies, their interaction, and age and education cohort dummies are not reported.

use, electricity. These tables provide evidence of negative price effects for choosing a particular type of energy.

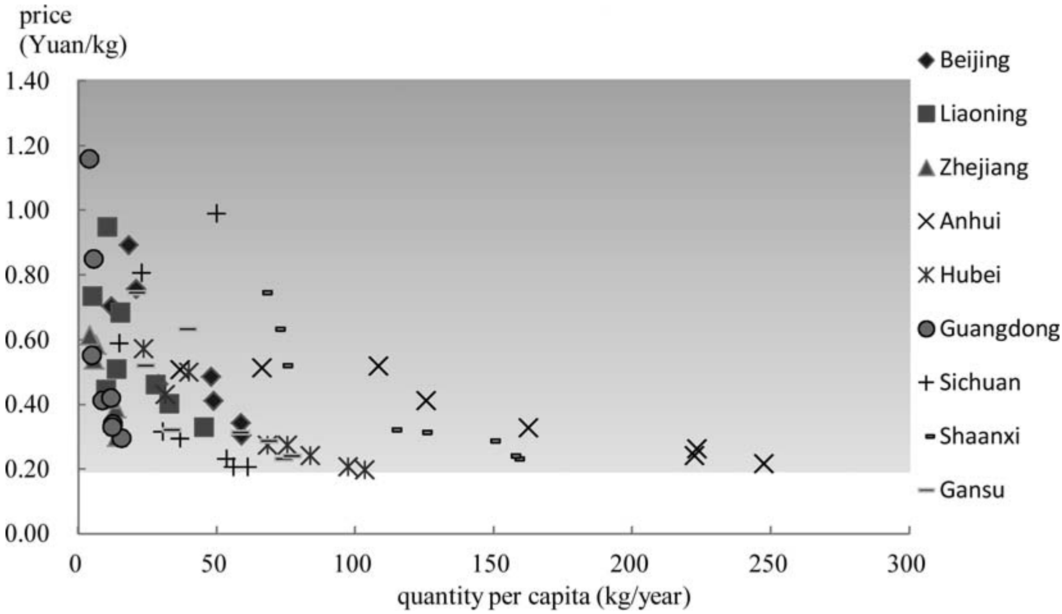
As noted above, we estimate the coal probit only for the low-income group. Households with higher expenditures on energy, or larger household sizes, are more likely to consume all types of energy. Old people with low incomes have a higher probability of choosing coal. Low-income households whose head works in a nonpublic company are more likely to use coal. Households with a female head are less likely to choose coal.

For the middle- and high-income groups, higher gasoline prices significantly (at the 1% level) reduce the probability of its use. The higher the total energy expenditures, the higher the probability of consuming gasoline. For the middle- and high-income groups, larger households and those with children have a higher probability of consuming gasoline.

Household size and children in the household have larger effects for the high-income compared with the middle-income group. Having young children (0–12 years old) has a greater effect on the choice of gasoline than having older children. Younger heads of households are more likely to consume gasoline in the middle- and high-income groups, and households with male or publically employed heads are also more likely to use gasoline.

Although commercial gas is available in most parts of urban China, not every household uses it; we find significant demographic effects, as Table 7 shows. Larger low- and middle-income

Figure 1: Price and Consumption of Coal by Province (2002–2009)



Note: coal prices are deflated using CPI

households are more likely to use gas, whereas larger high-income households are not. Low-income female-headed households are more likely to use gas than coal. Households with a publically employed head are more likely to use gas because it is cheaper, particularly in the low-income group, as shown in Table 3.

4.3. Price and Expenditure Elasticities by Expenditure Group

We begin by noting an interesting correlation for coal prices in this CUHS data set; in Figure 1, we plot average provincial coal prices versus the mean per capita coal consumption. The prices over time are deflated using the CPI. There is a strong negative correlation between price and consumption that runs both across provinces at a point in time, and within provinces over time. This negative correlation results from provincial coal endowments and local government pricing policies.

The results of estimating the AIDS system for each of the three income groups are given in Tables 8, 9 and 10. Demographic characteristics affect household energy consumption significantly in various ways; households with more family members spend relatively more on electricity and less on coal and/or gasoline. Employment status is significant; poor households with publically employed heads spend relatively more on electricity and less on coal, whereas those in the middle- and high-income groups use more electricity because its prices are lower, and these groups use less gas. Recall their higher share of expenditures devoted to dining out, which lowers gas usage for cooking. Public employees in the middle-income group consume less gasoline but those in the high-income group consume more. Younger people use less gas and more electricity in the middle- and high-income groups, which may be attributable to their lifestyle of dining out and using more

Table 8: Estimates of LES-AIDS Model for Low Expenditure Group

VARIABLES	Low Income Group		
Share of	Electricity	Coal	Gas
Price electricity	0.0479***	−0.0229***	−0.0244***
	(0.0103)	(0.0089)	(0.0040)
Price coal	−0.0229***	−0.0389***	0.0628***
	(0.0089)	(0.0084)	(0.0036)
Price gas	−0.0244***	0.0628***	−0.0375***
	(0.0040)	(0.0036)	(0.0028)
Log of energy expenditure	−0.0562***	0.0565***	−0.0006
	(0.0033)	(0.0023)	(0.0027)
Household size	0.0032	−0.0077***	0.0046**
	(0.0025)	(0.0026)	(0.0020)
Public sector: household head	0.009***	−0.0074***	−0.0016
	(0.0030)	(0.0028)	(0.0031)
Has child	0.0102**	0.0011	−0.0112***
	(0.0030)	(0.0025)	(0.0030)
Household head's age 35–54	−0.0028	−0.0028	0.0043
	(0.0047)	(0.0043)	(0.0046)
Household head's age 55 +	−0.0030	0.0118**	−0.0088
	(0.0058)	(0.0056)	(0.0061)
Has heating system	0.0262***	−0.0210***	−0.0051
	(0.0061)	(0.0054)	(0.0062)
Number of refrigerator: 1	0.0394***	−0.0525***	0.0133***
	(0.0042)	(0.0035)	(0.0038)
Number of refrigerator: 2 +	0.0335**	−0.0536***	0.0200
	(0.0143)	(0.0130)	(0.0147)
Has moped	0.0211***	−0.0065	−0.0149**
	(0.0064)	(0.0056)	(0.0063)
Number of Color TV: 2 +	0.0040	−0.0018	−0.0019
	(0.0039)	(0.0035)	(0.0041)
Number of air-conditioner: 1	0.0144***	−0.0208***	0.0076*
	(0.0042)	(0.0036)	(0.0040)
Number of air-conditioner: 2 +	0.0316***	−0.0189***	−0.0117
	(0.0079)	(0.0061)	(0.0079)
Housing size (m^2)	0.0004***	−0.00001	−0.0004***
	(0.0000)	(0.00004)	(0.0000)
Inverse Mill's ratio	N	Y	Y
Observations	23,503	23,503	23,503

Standard errors in parentheses: *** $p<0.01$, ** $p<0.05$, * $p<0.1$
Note: provincial dummies, year dummies, and the interactions are not reported.

electronic and electrical appliances. Older people in the middle-income group use less gasoline, whereas older people in high-income households use more.

The coefficients from Tables 8–10 are used to compute the conditional elasticities of demand, which are presented in Table 11. The standard errors are calculated by the bootstrap method which is widely used including Alexander et al. (2010), Kebede (2012), Li and Maddala (1999), Sam and Yi (2010), and Simar and Paul (2009). For each income group, the conditional own-price elasticities are of the expected sign and significant at the 1% level; however, most cross-price elasticities are small or insignificant. Poor households are price sensitive with respect to the coal price, given the strong patterns shown in Figure 1.

Unconditional elasticities of demand are shown in Table 12. The standard errors are calculated using bootstrap method introduced by Green, William, and David (1987). For all income

Table 9: Estimates of LES-AIDS Model for Medium Expenditure Group

VARIABLES	Medium income group		
Share of	Electricity	Gas & coal	Gasoline
Price electricity	0.0578***	0.0262***	−0.0834***
	(0.0119)	(0.0059)	(0.0117)
Price gas & coal	0.0262***	−0.0160***	−0.0564***
	(0.0059)	(0.0016)	(0.0043)
Price gasoline	−0.0834***	−0.0564***	0.1390***
	(0.0115)	(0.0043)	(0.0105)
Log of energy expenditure	−0.0565***	−0.0365***	0.0918***
	(0.0023)	(0.0022)	(0.0016)
Household size	0.0397***	0.0003	−0.0400***
	(0.0023)	(0.0013)	(0.0022)
Public sector: household head	0.0314***	−0.0263***	−0.0049***
	(0.0019)	(0.0018)	(0.0015)
Has child	0.0160***	−0.0190***	0.0038***
	(0.0020)	(0.0018)	(0.0014)
Household head's age 35–54	−0.0366***	0.0376***	−0.0008
	(0.0033)	(0.0028)	(0.0018)
Household head's age 55 +	−0.0820***	0.0826***	−0.0008
	(0.0036)	(0.0030)	(0.0021)
Has heating system	−0.0216***	0.0268***	−0.0055**
	(0.0048)	(0.0036)	(0.0028)
Number of refrigerator: 1	0.0550***	−0.0543***	−0.0009
	(0.0034)	(0.0030)	(0.0021)
Number of refrigerator: 2 +	0.0728***	−0.0706***	−0.0029
	(0.0062)	(0.0058)	(0.0039)
Has moped	0.0434***	−0.0174***	−0.0228***
	(0.0030)	(0.0026)	(0.0018)
Number of Color TV: 2 +	0.0196***	−0.0162***	−0.0032**
	(0.0028)	(0.0017)	(0.0014)
Number of air-conditioner: 1	0.0454***	−0.0442***	−0.0028
	(0.0021)	(0.0020)	(0.0016)
Number of air-conditioner: 2 +	0.0860***	−0.0886***	0.0025
	(0.0028)	(0.0026)	(0.0017)
Housing size (m^2)	0.0003***	−0.0002***	−0.0001***
	(0.0000)	(0.0000)	(0.0000)
Inverse Mill's ratio	N	Y	Y
Observations	69,042	69,042	69,042

Standard errors in parentheses: *** $p<0.01$, ** $p<0.05$, * $p<0.1$
Note: provincial dummies, year dummies, and the interactions are not reported.

groups, demand is price inelastic with respect to its own price. Own price-elasticities for electricity do not vary much across income groups; however, those of gas vary quite a lot. Higher income households are less price elastic for gas consumption while the poorer ones are somewhat price elastic. For the poor group, the price elasticity for coal is high (−0.950), and the cross-price elasticities have positive signs, implying that electricity and gas are substitutes for coal. Rich households are price-inelastic with respect to gasoline. Most of the unconditional price elasticities are of the expected sign and significant at the 1% level.

The estimates of expenditure elasticities in the energy group are also of the expected sign and significant at the 1% level. Coal is the most income elastic energy commodity for poor people, while for the rich, gasoline is more income elastic than other types of energy.

Table 10: Estimates of LES-AIDS Model for High Expenditure Group

VARIABLES	High income group		
Share of	Electricity	Gas & coal	Gasoline
Price electricity	0.0154	0.0224**	−0.0385*
	(0.0227)	(0.0111)	(0.0231)
Price gas & coal	0.0136**	−0.0154***	0.0009
	(0.0061)	(0.0036)	(0.0050)
Price gasoline	−0.0278	−0.0079	0.0358*
	(0.0219)	(0.0106)	(0.0200)
Log of energy expenditure	−0.0354***	−0.1050**	0.1390***
	(0.0032)	(0.0028)	(0.0024)
Household size	0.0717***	−0.0180***	−0.0436***
	(0.0043)	(0.0026)	(0.0046)
Public sector: household head	0.0194***	−0.0262***	0.0062*
	(0.0040)	(0.0030)	(0.0033)
Has child	0.0042	−0.0010	0.0060
	(0.0052)	(0.0038)	(0.0044)
Household head's age 35–54	−0.0428***	0.0016	0.0434***
	(0.0098)	(0.0085)	(0.0088)
Household head's age 55 +	−0.0572***	0.0328***	0.0245**
	(0.0136)	(0.0099)	(0.0115)
Has heating system	−0.0108	0.0088	0.0018
	(0.0084)	(0.0062)	(0.0076)
Number of refrigerator: 1	0.0018	0.0065	−0.0052***
	(0.0126)	(0.0099)	(0.0012)
Number of refrigerator: 2 +	0.0098	0.0093	−0.0187
	(0.0135)	(0.0108)	(0.0124)
Has moped	0.0384***	−0.0016	−0.0387***
	(0.0053)	(0.0038)	(0.0048)
Number of Color TV: 2 +	0.0363***	−0.0176***	−0.0172***
	(0.0033)	(0.0028)	(0.0030)
Number of air-conditioner: 1	0.0356***	−0.0321***	−0.0035
	(0.0067)	(0.0064)	(0.0050)
Number of air-conditioner: 2 +	0.0622***	−0.0533***	−0.0098*
	(0.0068)	(0.0047)	(0.0052)
Housing size (m^2)	0.0004***	−0.0001***	−0.0002***
	(0.0000)	(0.0000)	(0.0000)
Inverse Mill's ratio	N	Y	Y
Observations	22,814	22,814	22,814

Standard errors in parentheses: *** p < 0.01, ** p < 0.05, * p < 0.1
Note: provincial dummies, year dummies and the interactions are not reported

We next compare our results with the price and income elasticities estimated for other countries which we summarize in Appendix Table A2. We can first conclude that the elasticities of energy demand for developing countries are higher than that of developed countries, which suggests that households in developing countries are more sensitive to prices and so may have a significant potential for energy saving.

Our estimates of electricity price elasticity are from −0.49 to −0.57, which is lower than estimates of other developing countries but higher than some of the other Chinese estimates given in Table A2. The estimates of electricity income elasticities in this paper are from 0.64 to 0.80, much higher than those for developed countries and but within the range those for developing countries. Our estimates of gas price elasticity are from −0.46 to −0.94, and income elasticities of

Table 11: Conditional Price and Income Elasticities by Expenditure Group

	Conditional price elasticity (Poor Group)		
	electricity	gas	coal
electricity	−0.870***	−0.053***	−0.041***
	(0.021)	(0.009)	(0.020)
gas	0.015	−1.132***	0.087***
	(0.017)	(0.009)	(0.005)
coal	0.007	0.032***	−1.050***
	(0.024)	(0.009)	(0.010)
	Conditional price elasticity (Middle Income Group)		
	electricity	Gas & coal	gasoline
electricity	−0. 859***	0.110***	−0.039***
	(0.018)	(0.013)	(0.008)
Gas & coal	0.158***	−0.962***	−0.051***
	(0.008)	(0.008)	(0.003)
gasoline	−0.109***	0.029***	−0.982***
	(0.020)	(0.011)	(0.001)
	Conditional price elasticity (Rich group)		
	electricity	Gas & coal	gasoline
electricity	−0.906***	0.368***	−0.034*
	(0.036)	(0.035)	(0.018)
Gas & coal	0.032**	−0.677***	−0.000
	(0.011)	(0.020)	(0.005)
gasoline	−0.086**	0.257***	−0.908***
	(0.041)	(0.037)	(0.014)
	Conditional expenditure elasticity		
	electricity	gas	Coal
low	0.896***	0.946***	1.071***
	(0.006)	(0.007)	(0.004)
	electricity	Gas & coal	Gasoline
medium	0.906***	0.924***	1.064***
	(0.005)	(0.004)	(0.010)
high	0.934***	0.673***	1.108***
	(0.005)	(0.009)	(0.003)

gas or gas & coal demand range between 0.57 and 0.67. Both estimates are higher than those of developed countries but within the range of that of developing countries. The price elasticities of gasoline estimated here are from −0.85 to −0.94, and the income elasticities of gasoline demand are between 0.76 and 0.94; both are relatively higher than those of other countries. Coal is rarely used in urban China now, especially in rich regions. It is estimated that the price and income elasticities of coal demand are −0.95 and 0.76 respectively, which are similar to the estimates in the other studies.

5. CONCLUSION

We estimated the residential energy demand system in urban China using detailed micro-level household survey data, and using a two-stage budgeting framework that allowed for a simple

Table 12: Unconditional Price and Income Elasticities by Expenditure Group

	Unconditional price elasticities (low expenditure group)		
	Electricity	Gas	Coal
electricity	−0.573***	0.261***	0.315***
	(0.021)	(0.009)	(0.020)
gas	0.197***	−0.939***	0.304***
	(0.017)	(0.009)	(0.005)
coal	0.090***	0.121***	−0.950***
	(0.024)	(0.008)	(0.010)
	Unconditional price elasticities (medium expenditure group)		
	Electricity	Gas & coal	Gasoline
electricity	−0.548***	0.427***	0.326***
	(0.018)	(0.013)	(0.009)
Gas & coal	0.391***	−0.724***	0.223***
	(0.008)	(0.008)	(0.004)
gasoline	−0.075***	0.064***	−0.942***
	(0.020)	(0.011)	(0.001)
	Unconditional price elasticities (high expenditure group)		
	Electricity	Gas & coal	Gasoline
electricity	−0.494***	0.665***	0.455***
	(0.036)	(0.036)	(0.018)
Gas & coal	0.339***	−0.456***	0.364***
	(0.011)	(0.020)	(0.005)
gasoline	−0.039	0.290***	−0.854***
	(0.041)	(0.037)	(0.014)
	Unconditional expenditure elasticity		
	Electricity	Gas	Coal
Low income	0.638***	0.674***	0.763***
	(0.012)	(0.013)	(0.014)
	Electricity	Gas & coal	Gasoline
medium	0.646***	0.659***	0.759***
	(0.007)	(0.007)	(0.010)
high	0.796***	0.573***	0.944***
	(0.011)	(0.010)	(0.013)

but complete accounting of all nondurable consumption items. Prior to this study, such a set of national microdata has not been used to estimate Chinese household demand. We made a special effort to include the housing consumption value which is not adjusted appropriately in either the official expenditure survey or in other national surveys.

We find that consumption patterns differ significantly by household size, age of the head of the household, the presence and age of children and the employment status of the head of the household. We also find that energy consumption has a low income elasticity.

Electricity and gas are cleaner and available to most urban households today, and are widely used. In addition, middle- and high-income groups consume little coal today, but coal continues to constitute nearly 20% of the total energy expenditures of low-income households. Given overall income levels in China, the middle- and low-income groups consumed very little gasoline in 2008, whereas gasoline comprised more than 20% of the total energy consumption in high-income households. This number might be understated considering that a large part of gasoline consumption is paid by employers.

Our estimated elasticities show that poor households are very sensitive to the price of coal and that rich households are sensitive to the price of gasoline. Each of the three groups is price inelastic for gas and electricity.

The results of this type of research are important for analyzing government policies regarding energy use and the environment, such as carbon control policies and gasoline taxes. A better understanding of household behavior is necessary to estimate the impacts of policies that affect energy prices. As incomes rise and more automobiles are put into use, rising vehicle emissions in China will continue to add to the already serious air pollution problem. Given that the estimated gasoline price elasticity is close to one, higher gasoline taxes may be an effective way to reduce pollution.

In addition, the Chinese government has invested heavily in electricity and pipe infrastructure. Given our estimated elasticities for electricity, gas and coal, it would appear to be good policy to make piped gas even more widely available to help make the transition toward cleaner fuels.

Although there are a number of data issues such as the small sample of rich households surveyed and the adjustments for owner-occupied housing, and the various simplifications we had to make in constructing the data series—particularly for the time series to identify the first-stage function—we believe that we have obtained plausible estimates of household demand behavior in urban China and that we have laid the groundwork for future improvement in data analysis and econometric work. Our estimates also offer a better basis for projecting energy demand and thus for designing energy policies.

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APPENDIX

Table A1: Data Sources for Prices

	Consumption item	Data source
first stage	Price of energy basket	Aggregate coal, electricity, gas and gasoline from 2nd stage
	Price of non-energy basket	Provincial CPI for goods and services, excluding energy
second stage	coal	household unit price (value divided by quantity)
	electricity	household unit price (value divided by quantity)
	Gas (coal gas, piped petroleum gas, natural gas, bottled LPG)	City or county level data surveyed by National Development and Reform Commission
	gasoline	household unit price from CUHS in 2008 to calculate county level price, combined with provincial gasoline prices from International Petroleum Economics

Table A2: Summary of Price and Income Elasticities in Other Studies

Energy type	Author	Country	Price elasticity	Income elasticity
Electricity	Paul et al. (2009)	U.S.	−0.11 to −0.15 (short-run) −0.32 to −0.52 (long-run)	0.11
	Alberini and Filippini (2011)	U.S.	Short-run: −0.15 Long-run: −0.73	0.05
	Fell et al. (2014)	U.S.	−0.50	0.01
	Blázquez et al. (2013)	Spanish	Short-run: −0.07 Long-run: −0.19	SR: 0.23 LR: 0.61
	V. Bianco et al (2009)	Italy	−0.06	
	M.-F. Hung, T.-H. Huang (2015)	Taiwan	Summer −0.454 Non-summer −0.857	S 0.291 Non-S 0.205
	Gundimeda, Köhlin (2008)	India	−0.590 to −0.715	0.533–0.895
	Zhou and Teng (2013)	China	−0.35 to −0.50	0.14 to 0.33
	Shi, Zheng and Song (2012)	China	−0.15	1.06
Gas	Tveterås (2015)	OECD	−0.003 to −0.223	−0.26 to 1.59
	Meier and Rehdanz (2010)	U. K.	−0.34 to −0.56	0.01 to 0.06
	Rehdanz (2007)	Germany	−0.63 to −0.44	
	Maddala et al. (2001)	U.S.	−0.312 to −0.129	
	Gundimeda, Köhlin (2008)	India	−0.484 to −1.05	0.556–0.989
	Iootty et al. (2004)	Brazil	−0.420	0.505
	Yihua Yu, Xinye Zheng,Yi Han (2014)	China	−1.016 to −2.186	−0.194 to 0.229
Gasoline	Z. Wadud et al. (2010)	U.S.	−0.016 to −0.576	0.284 to 0.433
	L. Flood et al.(2010)	OECD	−0.077 to −0.117	0.071–0.073
	W. Liu (2014)	U.S.	−0.062 to −0.083	0.16 to 0.21
	C.-Y.Cynthia Lin, Jieyin(Jean) Zeng (2013)	China	−0.497 and −0.196	1.01 and 1.05
Coal	Reddy (1975)	U.S.	−0.371 to −0.974	
	Goldstein and Smith (1976)	U.S.	−0.480 to −0.316	
	Kezhong Zhang et al. (2011)	China	−0.34	
	Burke & Liao (2015)	China	−0.3 to −0.7	1.2 to 1.7