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On the demand for natural gas in urban China

Yihua Yu*, Xinye Zheng, Yi Han

Department of Energy Economics, Renmin University of China, Beijing, China

HIGHLIGHTS

- We estimate the price and income elasticities of residential demand for natural gas.
- We use a set of unbalanced panel data for Chinese's cities during 2006–2009.
- We use a feasible generalised least squares approach.
- We find that natural gas consumption is price elastic and income inelastic.
- We find large variations in demand behaviours across China's regions.

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ABSTRACT

Using a set of unbalanced panel data for Chinese's cities during the period of 2006–2009, this study aims to estimate the price and income elasticities of residential demand for natural gas. Natural gas consumption is specified as a function of its own price; substitute prices; urban wages; and other supply, climate, and housing characteristics. Using a feasible generalised least squares (FGLS) technique, which controls for panel heteroskedasticity and panel correlation, we find that natural gas consumption is price elastic and income inelastic when other covariates (e.g., the supply of natural gas pipeline and heating degree days) are controlled. In addition, there are large variations in demand behaviours across China's regions. There is a substantial income effect on demand for natural gas in southern China, whereas the northern regions are found to have a higher price effect. In addition, the substitution effect between coal and natural gas is significant in North China but is not significant in South China. These findings have several important policy implications for natural gas pricing and supply cost analysis in the context of China.

1. Introduction

China's demand for and production of natural gas have risen substantially in the past decade. In 2011, the country consumed 111.63 billion cubic meters (bcm), up approximately 15% from 2010, more than tripling consumption over the last decade, according to Tables 3–8 and 4–22 of China Energy Statistics Yearbook (NSB (National Statistical Bureau), 2012). By contrast, China produced 94.85 billion cubic meters of natural gas. Although natural gas use is rapidly increasing in China, the fuel comprised less than 5% of the country's total primary energy consumption in 2011. China's energy usage remains dominated by fossil fuel, particularly coal, which accounts for approximately 70% of China's total primary energy consumption. The U.S. Energy Information Administration (EIA (Energy Information Administration), 2012) hereafter reported that "China is the world's most populous country and the largest energy consumer in the world. Rapidly increasing energy demand has made China extremely influential in world energy markets." In the near future, along with the rapid urbanisation and strong economic growth occurring in China, demand for natural gas is expected to continue to grow quickly, which may intensify the imbalance between the supply and demand of natural gas. Hence, to gain a better understanding of the supply-demand imbalance problem and the natural gas consumption behaviour of the entire nation, this paper analyses residential natural gas demand in China's cities using a log-linear panel model, which allows for own-price, cross-price, and income elasticity estimates.

The existing literature references a number of studies on the price and income elasticities of natural gas (and other fuels) demand at the national, state, and local levels. Appendix A summarises some of the major works over the last two decades. In general, studies on the U.S. economy represent by far the largest share of the relevant literature. Only a few studies focus on Asian regions, and almost none target African regions. In terms of types of data that are covered, these studies can be generally classified into three types: cross-sectional data, time-series aggregated data,

* Corresponding author. Tel.: +86 10 82500322; fax: +86 10 62511091.
E-mail address: yihua.yu@ruc.edu.cn (Y. Yu).

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and cross-section time-series data (panel, or longitudinal data). Pure cross-section data have many limitations (Kramer, 1983). For example, such data represent one historical context at a particular time. By contrast, single time series data allow for multiple historical contexts but only one spatial location. Panel data are able to combine both features of cross-sectional data and time series data. That is, panel data contain observations of multiple phenomena obtained over multiple time periods for the same firms or individuals. Econometrically, panel data control for possible individual unobserved heterogeneity that drives the demand for natural gas. Cross-sectional studies include Yooa et al. (2009), who use 2005 survey data to estimate the residential demand for natural gas in Seoul. Time series studies include Bernstein and Madlener (2011), Berndt and Watkins (1997), and Payne et al. (2011). Using time series data for 12 member countries from the Organization for Economic Cooperation and Development (OECD), Bernstein and Madlener (2011) use the autoregressive distributed lag (ARDL) technique to examine the long-term and short-term elasticities of demand for natural gas. Furthermore, they apply the fully modified ordinary least squares (FMOLS) and dynamic ordinary least squares (DOLS) approaches for robustness checks. Payne et al. (2011) apply a similar approach for U.S. Illinois data for 1959 and 1974 to study the demand price elasticity of natural gas. Berndt and Watkins (1997) uses time series data for the years 1959 and 1974 and the maximum likelihood estimation (MLE) method to estimate the price and income elasticities of natural gas in Canada. Other studies use panel data to examine the demand price elasticity of natural gas. Beierlen et al. (1981) and Herbert (1986) focus on northern U.S. states, and Garcia-Cerrutti (2000) focuses on the towns in California from 1983 to 1997. Other panel data studies include Balestra and Nerlove (1966), Liu (1983), Lin et al. (1987), Maddala et al. (1997), Berkhout et al. (2004), Bernsrein and Griffin (2006), Joutz et al. (2009) and Alberini et al. (2011).

Turning to the empirical results, these studies can be summarised in the following two ways. First, the demand price elasticity is negative, both in the short run and the long run, and the short-run price elasticity is smaller (in absolute terms) than the long-run elasticity. In addition, the short-run own-price elasticity ranges from -0.7 to -0.04, whereas the long run price elasticity ranges from -3.4 to -0.1. Second, most studies (except Berkhout et al. (2004), Maddala et al. (1997) and Garcia-Cerrutti (2000)) find that the income elasticity of natural gas consumption is positive; that is, natural gas is a normal good. The short-run income elasticity ranges from 0.2 to 0.81, whereas the long-run income elasticity ranges from 0.1 to 3.32. In other words, demand for natural gas is less affected by income variation in the short run than it is in the long run.

Using a set of unbalanced panel data for Chinese's cities during the period of 2006–2009, this study aims to estimate the price and income elasticities of residential demand for natural gas. Natural gas consumption is specified as a function of its own price; substitute prices; urban wages; and other supply, climate, and housing characteristics. Using a feasible generalised least squares (FGLS) technique, which controls for panel heteroskedasticity and panel correlation, we find that natural gas consumption is price elastic, as well as income inelastic when other covariates (the supply of natural gas pipelines, heating degree days, etc.) are controlled. In addition, there are large variations in demand behaviours across China's regions. There is a substantial income effect on the demand for natural gas for southern China, whereas the northern regions are found to have a higher price effect. In addition, the substitution effect between coal and natural gas is significant in North China, but that is not the case in the South China. These findings have several important policy implications for natural gas pricing and supply cost analysis in the context of China.

This study contributes to the existing energy demand literature in at least two respects. First, although there are numerous studies on the determinants of the demand for natural gas in other countries, there are much fewer studies on China's natural gas demand. To the best of our knowledge, only two studies have attempted to estimate the elasticities of China's natural gas demand. Gao et al. (2012) estimated the price elasticity of natural gas using time series data (78 months) from the city of Chengdu (in the province of Sichuan) and found that the price elasticity is inelastic (0.07–0.59) in the short and very elastic (2.29–2.58) in the long run. Zheng (2012), using data from Shanghai, found that the price elasticity is inelastic in both the short run and the long run. Although both studies provide some insightful information on understanding China's natural gas market from a regional perspective, both also suffer from several drawbacks. For instance, the very high elasticities from Gao et al. (2012) could be due to the omission of several important control variables, whereas the inelastic price elasticities found in Zheng (2012) could be partially due to the insufficient sample size (only 10). This study tries to fill that void by using panel data (which have both cross-sectional and time series dimensions) from a national perspective and a comprehensive set of control variables to estimate the price and income elasticities of residential demand for natural gas. Second, this study constitutes an important basis for other research, such as a computable general equilibrium (CGE) analysis of China's natural gas market (because it provides the required parameter estimates (e.g., the cross-price substitution parameter)) or energy demand forecasting analysis.

The rest of the paper is organised as follows. Section 2 provides a simple theoretical model of residential demand for electricity. Section 3 presents the empirical specification of the electricity demand model, describes the data used in the analysis, and outlines the econometric estimating issues. Section 4 reports the empirical results. Section 5 summarises the primary findings and offers several concluding remarks.

2. A simple theoretical model of residential demand for natural gas

The extensive body of literature on urban residential demand for natural gas, as presented in Table A in the appendix, suggests that natural gas demand is determined by various factors. Based on this assumption, we can derive residential demand for natural gas using the traditional framework of household production theory, which was introduced by Becker (1965), Lancaster (1965) and Muth (1966). According to household production theory, households do not demand natural gas for direct consumption; rather, they use it to produce a series of final goods and services (hot water, cooked food, heating, etc.). In other words, households purchase goods (natural gas in this study) on the market to serve as inputs in the production process to obtain goods (say, cooked food) that are useful for households. Related to this study, we can consider households to combine natural gas, electricity, and capital stock (i.e., appliances) to produce a composite energy good.

Borrowing on Filippini's (1999) model, the production function of the final energy good (x) can be defined as a function of the natural gas consumed (n), the electricity or liquefied-petroleum gas consumed (g), and the stock of household appliances (cs):

$$x = x(n, g, cs). \tag{1}$$

The representative household is assumed to have the utility function (u), which has the usual properties of differentiability and curvature and can be expressed as a function of the composite energy good (x), the purchased composite numéraire good (y), and household characteristics (i.e., the age of the house, number of bedrooms, and lot size) (z)

$$U = U(x, y, z). \tag{2}$$

In this framework, in each period, the household's decision can be considered a problem of optimisation with two stages (Muellbauer, 1974; Deaton and Muellbauer, 1980). In the first stage, consumers behave as a firm whose goal is to minimise the costs of producing the energy good. In the second stage, the firm's goal is to maximise its utility. Hence, the problem for the consumer in the first stage can be expressed as follows:

$$\begin{aligned} &Min\ p^n n + p^g g + p^{cs} cs \\ &s.t\ x = x(n, g, cs), \end{aligned} \tag{3}$$

where p^n is the price of natural gas, p^g the price of the electricity/liquefied-petroleum gas, and p^{cs} the price of capital stock. Solving for the constrained optimisation problem (via Lagrangian methods) gives us the optimal cost function (C^*)[1]

$$C^* = C^*(p^n, p^g, p^{cs}), \tag{4}$$

which has the following properties (Varian, 1992): linearly homogeneous x and factor prices (p^n, p^g, p^{cs}), an increasing x, and non-decreasing and concave factor prices.

Applying Shephard's (1953) lemma yields the derived input demand or Hicks (1939) demand function for natural gas

$$e = \partial C^*(p^n, p^g, p^{cs})/\partial p^e = e(p^n, p^g, p^{cs}, x). \tag{5}$$

In the second stage, the household maximises its utility, subject to its budget constraint

$$\begin{aligned} &Max\ U(x, y, z) \\ &s.t\ C(p^n, p^g, p^{cs}, x) + y = I, \end{aligned} \tag{6}$$

where I is the household income level. Solving this problem, we obtain the Marshallian demand functions (Marshall, 1890) for the goods x (and y as well)

$$x^* = x^*(p^n, p^g, p^{cs}, I; z). \tag{7}$$

Eventually, substituting the Marshallian demand function in the derived input demand function for natural gas yields the following:

$$e = e(p^n, p^g, p^{cs}, x^*(p^n, p^g, p^{cs}, I; z)) = e(p^n, p^g, p^{cs}, I; z). \tag{8}$$

In the following section, an empirical model will be specified to estimate the demand function for natural gas.

3. Model, data, and methodology

In this section, we specify the empirical model of residential demand for natural gas; describe the regression covariates used in this study, addressing some possible estimation issues; and identify the appropriate econometric method for estimating a panel data model.

3.1. Model and data

Using an unbalanced panel of Chinese cities for the period of 2006–2009, we write the empirical electricity consumption model as follows:

$$\begin{aligned} \ln G_{it} &= \theta_0 + \theta_1 \ln PG_{it} + \theta_2 \ln PE_{it} + \theta_3 \ln PLPG_{it} + \theta_4 \ln COAL_{it} \\ &\quad + \theta_5 \ln WAGE_{it} + \psi \ln Z_{it} + \mu_{it}, \\ \mu_{it} &= \nu_i + e_t + \varepsilon_{it}, i = 1, 2, \ldots, N, t = 1, 2 \ldots T. \end{aligned} \tag{9}$$

[1] The cost function C^* measures the minimal costs of producing x units of output when factor prices (p^n, p^g, p^{cs}) are given.

In the model, G_{it} indicates the per capita residential demand for natural gas for city i in year t. PG_{it}, $PLPG_{it}$, PE_{it}, and $COAL_{it}$ are the prices for natural gas, electricity, LPG, and steam coal, respectively, for city i in year t.[2] $WAGE_{it}$ is the averaged wage of urban employees in city i in year t. Z is a vector of control variables that are thought to influence the demand of natural gas, including (1) *FSIZE*, which measures the number of occupants in a family; (2) *HSIZE*, which measures the per capita dwelling area; (3) *HDD*, which indicates heating degree days, an index used to estimate the amount of energy (natural gas) required for space heating during the cool season ($HDD = (18\ ^\circ\mathrm{C} - R) \times D$ if R is less than or equal to the heating threshold of 18 °C or zero if R is greater than this threshold, where R is the averaged outdoor temperature over a period of D days); (4) *PIPE*, which measures the city's per capita length of natural gas pipelines. The natural gas market expanded quickly during our sample period, and, unlike other commodities, natural gas demand is constrained by supply. For urban residents, this not only requires a city connecting to the trunk pipeline but also the development of a distribution network within the city. Hence, the supply factor is controlled in the natural gas demand model. With respect to the coefficients to be estimated, θ_0 is the constant term, whereas θ_1–θ_5 can be interpreted, respectively, as the own-price elasticity of demand for natural gas, cross-price elasticity between natural gas and electricity, cross-price elasticity between natural gas and LPG, and income elasticity of demand for natural gas. μ_{it} is the composite term, which, in general, consists of three sources of variation: the unobservable individual effect ν_i (which is constant over time and different across units), the unobservable time effect e_t (which varies over time and is constant across units), and the idiosyncratic error term ε_{it}.

Descriptive statistics and data sources for the variables used in this study are reported in Table 1. It should be noted that there are a few observations missing when we combine several data sources, which leads us to eventually have an unbalanced panel dataset that covers only 62 cities, 33 of which are among China's top 70 cities (in terms of population size) and 29 of which are not (Appendix B). We are left with 216 observations for our final analysis. It is worth mentioning though that although the number of sample cities is much smaller than China's total number of cities (332 according to China Statistical Yearbook 2012), the sample cities are representative. In addition, statistical data from sample cities can be substantially different from the national average. Hence, the results obtained in this study should be interpreted in the context of China's major cities.

3.2. Estimation issues

This subsection discusses the model selection process for residential demand for electricity and provides empirical tests for panel group-wise heteroskedasticity and correlations across and within groups.

3.2.1. Model selection

Econometrically estimating the natural gas demand function presents certain challenges. For instance, simultaneity problems exist between marginal price and consumption if aggregated data are used or consumers face a nonlinear price scheme because there is reverse causality between demand and price. Fortunately, the simultaneity problem is avoided in this study because we use

[2] To the best of our knowledge, there have been no city data available for coal prices. To obtain a proxy for city-level coal prices, we assume that if a particular city is within the main coal-producing area, the city's coal price is equal to the mine-mouth price of steam coal. Otherwise, it is assumed to be equal to the port price, or the power-station coal price, depending on which one (port or power company) is proximate to the city.

Table 1
Descriptive statistics of variables used in the empirical study (Obs.=216; 2009=100).

Variable	Description	Mean	Std Dev	Min	Max
G	Natural gas usages (m^3/person)[a]	401.19	4,684.27	3.33	68,864.98
PG	Natural gas price (yuan/m^3, real)[b]	2.33	0.93	1.25	5.93
PE	Electricity price (yuan/kW h, real)[b]	0.55	0.05	0.42	0.71
PLPG	LPG price (yuan/m^3, real)	6.77	4.65	4.24	57.42
COAL	Coal price (yuan/t, real)[c]	481.14	160.08	179.06	950.95
WAGE	Wage of urban employees (yuan, real)[b]	28,520.70	8,226.12	14,924.97	63,545.73
HSIZE	Dwelling area (m^2/person)[d]	23.74	5.95	2.11	39.94
FSIZE	Family size (person/family)[d]	3.10	0.33	1.41	4.28
HDD	Heating degree days (unit-free)[e]	509.50	599.27	0.10	2,705.20
PIPE	Length of pipelines (km/person)[b]	5.01	3.36	0.20	14.93

[a] From China Urban Construction Statistical Yearbook (2006–2009), compiled by the Ministry of Housing and Urban–Rural Development.
[b] From the Price Monitoring Centre under the National Development and Reform Commission.
[c] Authors' calculation from China Coal Resource (http://en.sxcoal.com).
[d] From China Urban Life and Price Yearbook (2006–2010), (NSB (National Statistical Bureau), 2010).
[e] Authors' calculation from China Meteorological Data Sharing Service System (http://cdc.cma.gov.cn).

the household-level data, in which the household is clearly the price taker. In addition, natural gas prices are highly regulated in China. During our study period (2006–2009), consumers faced a single price scheme, which allowed us to avoid the endogeneity problem caused by a nonlinear pricing scheme.

There are several options for estimating Eq. (9): a pooled OLS, fixed effects, or random effects model. The pooled OLS method is usually not used in panel data settings because it assumes away significant individual or temporal effects among the panel. The fixed effects and random effects models assume there are unobserved specific individual and temporal effects but fails to capture the possible existence of serial and contemporaneous/cross-sectional (auto-) correlation and (group) heteroskedasticity in the sample. Hence, we are inclined to estimate the proposed model by generalised least squares to obtain consistent and efficient estimators.

Specifically, we use the popular Parks–Kmenta feasible generalised least squares (FGLS) model (Parks, 1967; Kmenta, 1986), which allows for within-city and between-city correlation and group-wise (city-level) heteroskedasticity. The model considers the first-order autoregressive model in which the random errors μ_{it} have the following characteristics

$$\begin{aligned}
&E({\mu_{it}}^2)=\sigma_{ii} \quad \text{(heteroskedasticity or non} \\
&\quad -\text{constant variance } \sigma \text{ for each } i), \\
&\quad E(\mu_{it}\mu_{jt})=\sigma_{ij} \quad \text{(a covariance specification allowing} \\
&\quad \text{for contemporaneous correlation among the disturbances)}, \\
&\quad \mu_{it}=\rho_i\mu_{i,t-1}+\varepsilon_{it} \quad \text{(first}-\text{order autoregression with} \\
&\quad \text{autoregressive parameter } \rho),
\end{aligned} \tag{10}$$

where

$$\begin{aligned}
&E(\varepsilon_{it})=0 \;\; \text{(zero}-\text{mean idiosyncratic error term)}, \\
&E(\mu_{i,t-1}\varepsilon_{jt})=0 \;\; \text{(zero covariance between non} \\
&\quad -\text{contemporaneous correlation among } \mu \text{ and } \varepsilon), \\
&E(\mu_{it}\varepsilon_{jt})=\varphi_{ij} \;\; \text{(a covariance } (\varphi) \text{ specification allowing} \\
&\quad \text{for contemporaneous correlation among } \mu \text{ and } \varepsilon), \\
&E(\varepsilon_{it}\varepsilon_{js})=0 \quad (s\neq t) \;\; \text{(zero covariance between non} \\
&\quad -\text{contemporaneous correlation among } \varepsilon\text{s}), \\
&E(\mu_{i0})=0 \;\; \text{(mean}-\text{zero initial disturbance)}, \\
&E(\mu_{i0}\mu_{j0})=\sigma_{ij}=\frac{\varphi_{ij}}{(1-\rho_i\rho_j)} \;\; \text{(a covariance specification allowing for} \\
&\quad \text{contemporaneous correlation among the initial disturbances)}.
\end{aligned} \tag{11}$$

In this model, the covariance matrix ($E(\mu\mu')$ or V) for the vector of random errors μ can be expressed as follows:

$$E(uu')=V=\begin{bmatrix} \sigma_{11}P_{11} & \sigma_{12}P_{12} & \dots & \sigma_{1N}P_{1N} \\ \sigma_{21}P_{21} & \sigma_{22}P_{22} & \dots & \sigma_{2N}P_{2N} \\ \dots & \dots & \dots & \dots \\ \sigma_{N1}P_{N1} & \sigma_{N2}P_{N2} & \dots & \sigma_{NN}P_{NN} \end{bmatrix} \text{ where}$$
$$P_{ij}=\begin{bmatrix} 1 & \rho_j & \rho_j^2 & \dots & \rho_j^{T-1} \\ \rho_i & 1 & \rho_j & \dots & \rho_j^{T-2} \\ \rho_i^2 & \rho_i & 1 & \dots & \rho_j^{T-3} \\ .. & \dots & \dots & \dots & \dots \\ \rho_i^{T-1} & \rho_i^{T-2} & \rho_i^{T-3} & \dots & 1 \end{bmatrix}, \tag{12}$$

FGLS follows the following procedure. First, we estimate the covariance matrix (V) with a two-stage procedure. The first step is to use ordinary least squares approach to estimate β and obtain the fitted residuals $\hat{u}=y-x\hat{\beta}_{OLS}$. A consistent estimator of the first-order autoregressive parameter is then obtained, as follows:

$$\hat{\rho}_i=(\textstyle\sum_{t=2}^{T}\hat{u}_{i\,t}\hat{u}_{i,t-2})/(\sum_{t=2}^{T}\hat{u}_{i,t-1}^2) \tag{13}$$

Next, the autoregressive characteristic of the data can be removed by the usual transformation of taking weighted differences. That is,

$$\begin{aligned}
&y_{i1}\sqrt{1-\hat{\rho}_i^2}=\textstyle\sum_{k=1}^{p}x_{i1k}\beta_k\sqrt{1-\hat{\rho}_i^2}+u_{i1}\sqrt{1-\hat{\rho}_i^2}, \\
&y_{i1}-\hat{\rho}_i y_{i,t-1}=\textstyle\sum_{k=1}^{p}(x_{itk}-\hat{\rho}_i x_{i,t-1,k})\beta_k+u_{it}-\hat{\rho}_i u_{i,t-1}, \text{ or}, \\
&y_{it}^*=\textstyle\sum_{k=1}^{p}x_{itk}^*\beta_k+u_{it}^*,
\end{aligned} \tag{14}$$

where p is the number of explanatory variables.

Second, the covariance matrix V is estimated by applying ordinary least squares to the preceding transformed model and obtaining $\hat{u}^*=y^*-x^*\hat{\beta}_{OLS}^*$, from which the consistent estimator of σ_{ij} is calculated as $s_{ij}=\hat{\varphi}_{ij}/(1-\hat{\rho}_i\hat{\rho}_j)$, where $\hat{\varphi}_{ij}=1/(T-p)\sum_{t=1}^{T}\hat{u}_{it}^*\hat{u}_{jt}^*$. Finally, the FGLS estimator can be written in concise matrix notation

$$\hat{\beta}_{FGLS}=(x'\hat{V}^{-1}X)^{-1}x'\hat{V}^{-1}y \tag{15}$$

3.2.2. Tests for panel heteroskedasticity and correlation

Empirically, to test for heteroskedasticity, the likelihood ratio (LR) test is employed by specifying *hetero* in the command *xtgls* in STATA (STATA Corp., 2005), which uses iterated GLS to estimate the model with heteroskedasticity. With respect to a test for autocorrelation, Wooldridge (2002) presented a simple test in panel data models, which was later advanced by Drukker (2003) in his simulation study. He found that the test has good size and power properties in reasonably sized samples. His written program is used in this paper to test for autocorrelation.

4. Empirical results

This section reports the empirical results of the residential demand model for the entire sample and two subsamples, namely, northern cities and southern cities, with the Yangtze River serving as the traditional division line. All cities located to the north (south) of the Yangtze River are grouped as the northern (southern) cities.

4.1. Whole sample results

The coefficients of the demand equation (Eq. (9)) estimated using the FGLS approach are reported in Table 2. Column 2 reports the results for the whole sample. That the statistics of the likelihood-ratio test for heteroskedasticity and the Wooldridge *F* test for autocorrelation are greater than the corresponding critical values justifies the usage of the FGLS method. Price elasticity, which is of the greatest interest in this study, is significant and bears the expected sign. The estimated own-price elasticity is −1.431 and statistically significant at the 1% level, which suggests that, ceteris paribus, a l% increase in the price of electricity will result in an approximately 1.43% decline in household consumption of natural gas. In other words, the demand for natural gas is price elastic. If evaluated at the mean, if the price of natural gas increases from 2.3 to 2.6 yuan, the demand for natural gas will fall from 401 to 396 m^3 per capita.

The income (wage) elasticity of demand for electricity is found to be 0.207 and statistically significant. This result implies that urban demand for natural gas is less responsive to levels of income. Because this elasticity is well below unity, income growth apparently results in a less-than-proportional increase in natural gas demand. This result suggests that natural gas is a necessity and is a small part of numerous goods in people's daily lives. Furthermore, in a rapidly developing country, such as China, where household incomes are expected to increase greatly in the foreseeable future, the demand for natural gas will rise, as anticipated.

As expected, the price of electricity demand influences natural gas consumption. In particular, the coefficient on the price of electricity demand is found to be positive in the demand model. A 1% rise in the price of electricity leads to 0.4% rise in the consumption of natural gas. This result implies that natural gas is a substitute good for electricity; they do not act independently, and there is a strong switching effect between these two sources of energy. Similarly, coal is found to be a substitute for natural gas, as reflected by the statistically significant and positive coefficient for the price of coal. The positive sign is expected because coal has been the main resource for heating in China. Gas heating has not been widespread until recently. In an effort to reduce pollution, China is scheduled to replace four coal-burning heating plants in the capital of Beijing with natural gas-fired ones by the end of the year 2014 (Reuters, 2013). However, the relatively small elasticity estimate (0.194) could be partially attributed to the high economic costs of switching between energy carriers (due to the high investment costs in heating infrastructure), inadequate public knowledge about available substitutes, or the limited availability of substitutes.

The cross-price elasticity of natural gas consumption with respect to LPG is found to be positive but statistically insignificant. One possible explanation is that an average family may choose just one type of energy demand between natural gas and LPG because they are so similar. In addition, because substitution technologies across different energies are limited, a family that has already bought one particular appliance that mainly uses one energy fuel (natural gas or LPG) may not consider replacing natural gas with LPG (or vice versa) in the short run. The coefficient for heating degree days (*HDD*) is negative and statistically significant at the 1% level, implying that relatively warmer cities have a stronger

Table 2
Natural gas demand in China (dependent variable: ln (residential natural gas usage), unbalances panel, feasible generalised least square model (FGLS) approach.

	Whole sample	North	South
Ln(PG)	−1.431[c]	−2.186[c]	−1.016[c]
	(0.034)	(0.280)	(0.109)
Ln(PE)	0.412[b]	0.221	0.434
	(0.157)	(0.586)	(0.366)
Ln(PLPG)	0.120	0.00785	0.513[b]
	(0.068)	(0.125)	(0.165)
Ln(COAL)	0.194[c]	0.780[c]	0.332[c]
	(0.039)	(0.153)	(0.068)
Ln(WAGE)	0.207[c]	−0.194	0.229[a]
	(0.063)	(0.149)	(0.089)
Ln(HSIZE)	0.007	0.002	−0.069
	(0.035)	(0.102)	(0.058)
Ln(FSIZE)	−0.406[a]	−1.642[c]	−0.050
	(0.166)	(0.355)	(0.217)
Ln(PIPE)	0.016[a]	0.047[c]	0.075[c]
	(0.006)	(0.012)	(0.011)
Ln(HDD)	−0.043[c]	0.195[b]	−0.130[c]
	(0.006)	(0.068)	(0.016)
Constant	2.272[c]	3.071[a]	−0.068
	(0.679)	(1.252)	(1.014)
Observations	216	114	102
Number of cities	62	33	29
LR Chi-squared test statistic for heteroskedasticity	5.7e+06[0.000]	8.0e+05[0.000]	3.5e+06[0.000]
Wooldridge *F*-test statistic for autocorrelation	59.3[0.000]	38.5[0.000]	42.1[0.000]

Standard errors are reported in parentheses. *p* values are reported in brackets.

[a] $p < 0.10$.
[b] $p < 0.05$.
[c] $p < 0.01$.

demand for natural gas. This finding is inconsistent with our expectation because the general view is that relatively warmer cities require less natural gas. One possible reason is that regional heterogeneity is not taken into account in the whole sample. It is well known that northern cities use either coal or natural gas as the main energy source for heating, whereas southern cities mainly use natural gas. In the following section, further analysis is performed in an attempt to tackle the regional heterogeneity issue.

The coefficient for family size (*FSIZE*) is negative. This result indicates that a larger family, all else constant, tends to demand less natural gas, which is inconsistent with our expectation. One tentative interpretation is that the usage of natural gas, to a certain extent, has a scale effect; adding one more person to the family tends to reduce the marginal usage of natural gas. House size (*HSIZE*) is found to have neither a positive nor a negative effect on natural gas demand.

Natural gas demand is found to be affected by supply as well, which is consistent with our expectation that the demand for natural gas is constrained by supply. In other words, urban residents demand the natural gas that is provided by gas pipelines, which requires not only that the city connects to the trunk pipeline but also the development of a distribution network within the city. It is expected that the greater the length of natural gas pipelines, ceteris paribus, the lower the equilibrium price will be, which in turn pushes up demand for natural gas.

4.2. Subsample results

Further analysis is performed to examine whether the (own or cross-) price and income elasticities are affected by different localities. In doing so, we iterate the aforementioned demand model by separating the whole sample into two subsamples, one for the northern region and the other for the southern region. The results for the two subsamples are reported in Columns 2 and 3 in Table 2.

Several key results from our regional division can be summarised. First, northern cities, on average, have a higher elasticity (in absolute terms) than southern cities. In terms of the demand for natural gas, the northern urban households respond more sensitively to price changes, whereas southern urban households respond more sensitively to income changes. Second, whereas a strong substitution effect is found between natural gas and coal for the northern cities, a stronger substitution effect is found between natural gas and LNG for the southern cities. In the north, the high sensitivity of northern residents to the price of natural gas is expected given that coal and natural gas are two major sources of energy for northern Chinese families and can be easily substituted. In the south, the stronger substitution effect between natural gas and LNG is expected given that more residents will replace LNG with natural gas (for cooking and water-heating) if the price of LNG rises. Third, HDD has a heterogeneous effect on the demand for natural gas across China's regions. Cooler cities in North China tend to use more natural gas for space heating, but this is not the case for South China.

5. Conclusions

Urban residential natural gas consumption can be affected by a number of factors, such as (1) the price of natural gas, (2) urban residents' wage levels, (3) the available energy mix (e.g., coal and LNG), (4) heating degree days, and (5) the length of natural gas pipelines. Although there are numerous studies on the determinants of the demand for natural gas in other countries, studies on China's natural gas demand (at a regional level) have not been reported. This study attempts to rectify this omission in the recent literature by estimating the demand for urban residential natural gas using Chinese city panel data and a feasible generalised least squares (FGLS) model to perform the following tasks: (1) provide own price, cross price, and income elasticity estimates, (2) identify the effects of gas pipelines and heating degree days on residential natural gas demand, and (3) re-evaluate how the above elasticity and impact estimates are affected by regional heterogeneity. Using annual data from 2006 to 2009, the FGLS approach reveals that natural gas consumption is price elastic and income inelastic when other covariates are controlled. That electricity demand is elastic with respect to the price (-1.43) in China is consistent with some international empirical evidence on residential demand in other countries (or regions) (see, for example, Pindyck (1979), Lin et al. (1987) and Maddala et al. (1997)).

This study has several important policy implications. First, the information regarding the income elasticity of demand for electricity can be used to forecast future demand for natural gas. In a rapidly developing country, such as China, one can expect to see large increases in household incomes in the next decade. Income increases, in turn, will increase residential demand for natural gas. Based on the currently available nominal wage data from 1995 to 2009, we ran a simple regression of real wages (2009=100) against time. The regression gave us the predicted model ln(per worker real wage)$=-214.928+0.112\times$year, which yields an annual growth rate of per worker real wages of 11.87%. Using such a growth rate, we predict that the per worker real wage in 2020 will be RMB 110,742. Combining the predicted wage in 2020 with the wage elasticity of 0.207 found in our empirical study, we expect that per capita residential demand for natural gas will reach 198 m^3 per capita, or 278 bcm assuming China continues to have a population size of 1.4 billion people.[3] Such information should be useful in the context of the Chinese government's goal of boosting the share of natural gas in relation to total energy consumption to 10% by 2020, which has been set by the Chinese government to alleviate high amounts of pollution from heavy coal use and diversify the fuel mix for the nation.

Second, the information regarding the price elasticity of natural gas demand can be used to provide reference on reforming the natural gas price regime and planning future exploration and production activities. Natural gas prices, such as other energy prices, are highly regulated. Natural gas is promoted as a substitute to coal due to its 'cleanness' and efficiency. The prices are relatively cheap compared to international markets, which has created some problems in the natural gas market, such as a demand-supply imbalance problem. On the demand side, relatively cheap prices fail to provide motivation for saving and efficient usage of natural gas. On the supply side, cheap prices provide no incentive for further production and technology improvements. Thus, a market-oriented mechanism may be adopted to solve this problem, with price serving as the tool. Although an increase in price discourages the use of natural gas on the demand side, as reflected by the elastic own-price elasticity found in this empirical work, it encourages additional exploration and production on the supply side. Overall, a price increase would bring the price back to a relatively lower equilibrium price level.

In the following respects, future research could be performed to make better statistical or political inferences. First, the FGLS approach used in this study may not be a proper method for forecasting purposes. Given that there have been numerous forecasting methods, further studies may compare the FGLS approach with an alternative approach to make better inferences.

[3] In 2005, Natural gas demand would reach 250 bcm, as predicted by ERI (Economic Research Institute); 138 bcm, as predicted by IEA in its Reference Scenario of World Energy Outlook 2008; or 210 bcm, as predicted by the China National Petroleum Corporation.

Second, the present analysis of natural gas demand at the national level can be extended to the regional or provincial level to differentiate regional variations in elasticity estimates. Third, the database used in this study may be poor in quality because it covers data for only 62 cities and a 4-year period span and several data are missing from the database. Future studies should be performed using comprehensive and representative databases with rich statistical information.

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Appendix A. Supplementary material

Supplementary data associated with this article can be found in the online version at http://dx.doi.org/10.1016/j.enpol.2014.03.032.

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