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Urban Residential Demand for Electricity in China by Income and Temperature Levels

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Abstract

This paper estimates urban residential electricity demand in China with six regional groups based on different income and temperature. The empirical results are as follows: First, electricity consumption decreases with higher electricity price. The price elasticity is the greatest in the low income and mild temperature regions. Second, electricity consumption increases with higher income. The income elasticities in the high income and cold regions are greater than other regions. Third, the government policy for controlling electricity consumption needs to consider decreasing price elasticity as income grows.

Keywords: demand for electricity, FD GMM, income elasticity, price elasticity, rebound effect
JEL classification codes: D100, D120, Q410

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Ⅰ. Introduction

Since the opening up and economic reform of China, its economy has continued rapid growth. As a benefit of rapid economic growth, the lives of Chinese people have gradually been electrified, and more electricity is used to replace traditional energy sources. Although Chinese people still use coal, a lot of families in China changed to use electricity for heating and air conditioning. From 2001 to 2011, per capita electricity consumption of residents in China grew from 145 kWh to 418 kWh. The average annual growth rate of residential electricity consumption was as high as 12%. However, few attempts have been made to estimate the elasticity of demand for electricity in China. Thus, the purpose of this paper is to estimate demand for electricity in China and then derive the elasticity of demand for electricity, especially in Chinese urban residential areas.

Urban residential electricity consumption in China shows unique characteristics such as different consumption patterns depending on income and temperature of the region. As Chinese living standard improves, urban residential electricity consumption increased rapidly. However, China shows big differences of income and temperature levels among regions, and regional differences result in large variations in electricity consumption. For example, Haikou, Sanya, and Guangzhou located in southern part of China are very warm, while Harbin, Changchun, and Shenyang located in the northern part have a lot of snow in winter. Shanghai, Shenzhen, Guangzhou and Chongqing have experienced difficulties in electricity consumption during the summer peak, which might be a potential risk in demand for urban residential electricity. From this peculiar topography of China, it is important to pay attention to the urban residential elasticity of demand for electricity at regional levels. Okajima and Okajima (2013) which estimates price elasticities of residential electricity demand in Japan reports large variations in the response of electricity consumption to price changes depending on income and temperature levels. To have a comprehensive understanding of Chinese behavior of electricity consumption and derive useful policy implications, we need to analgize the regional difference in electricity consumption with regard to income and temperature.

Since the demand for residential electricity is closely linked with price and income, there are many country specific studies on the price and income elasticities of electricity demand. Examples are studies on Australia (Narayan and Smyth, 2005), the United States (Bernstein and Griffin, 2005; Dergiades and Tsoulfidis, 2008; Paul et al., 2009; Nakajima and Hamori, 2010), South Korea (Ahn et al., 2016; Keum et al., 2018), Japan (Nakajima, 2010; Okajima and Okajima, 2013), Israel (Beenstock et al., 1999), Greece (Hondroyiannis, 2004), China (Zheng et al., 2003; Shen, 2011；Dong and Wu, 2011; Li et al., 2012; Shen, 2014; Yu and Li, 2014), Turkey (Halicioglu, 2007), South Africa (Ziramba, 2008), the Netherlands (Lijesen, 2007), and groups of several countries (Narayan et al., 2007).

Among regional studies of China, Shen (2011) estimates short-run and long-run price elasticities for urban residential electricity for the period 1985~2008 in Zhejiang[1] with a partial adjustment model. In his paper, independent variables are electricity price, disposable income, price of alternative fuels, and temperature. Dong and Wu (2011) estimates short-run and long-run price elasticities for residential electricity in China for 1985~2008 with a VECM using electricity price, income, and alternative fuels as independent variables. Li et al. (2012) estimates

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1) Zhejiang is an eastern coastal province of China.

the residential electricity in Beijing for 2009 with the weighted least square method. Although there are some studies on the price elasticity of demand for electricity in China using individual regional data or pooled data, different regional effects of China on electricity demand have not been analyzed with regional panel data. Thus, this paper aims to examine the variation of elasticities among regions based on different income and temperature, and to present policy implications for the electricity consumption.

The papers on electricity consumption with a partial adjustment model are typically subject to the endogenous problem where exogenous variables are correlated with residuals.[2] A standard approach to overcome the endogenous problem is to estimate the equation using instrumental variables (IV) method. There are three different approaches using the IV method to overcome the endogenous problem: generalized method of moments (GMM) (Okajima and Okajima, 2013; Fell et al., 2010; Alberini and Filippini, 2011; Shen, 2014), limited information maximum likelihood (Matsukawa et al., 1993; Beenstock et al., 1999; Dong and Wu, 2011; Shen, 2011), and two stage least squared method (Beenstock et al., 1999; Paul et al., 2009; Li et al., 2012; Zheng et al., 2003; Yu and Li, 2014). This paper analyzes the elasticities of electricity demand with GMM because GMM is well known to treat the endogenous problems in estimation with dynamic panel data satisfying the moment conditions. Among the GMM methods, we use the FD GMM (Arellano and Bond, 1991) since the dependent variable is not unit root.[3]

The studies on electricity demand analyze price elasticities for the long-run and short-run effects. To derive the long-run and short-run price elasticities, three

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2) In a partial adjustment model, a lagged dependent variable is included as a regressor, and this variable is endogenous to the fixed effects in the error term, which creates dynamic panel bias. (Okajima and Okajima, 2013, p.434).

3) The selection of FD GMM is explained in section 3.1.

econometric models are used: partial adjustment model (Bernstein and Griffin, 2005; Paul et al., 2009; Shen, 2011; Okajima and Okajima, 2013), ARDL model (autoregressive distributed lag model) (Halicioglu, 2007; Dergiades and Tsoulfidis, 2008; Zheng et al., 2003; Yu and Li, 2014), and error correction model (Hondroyiannis, 2004; Narayan and Smyth, 2005; Ziramba, 2008). In China, Shen (2011) shows short-run and long-run price elasticities for urban residential electricity with a partial adjustment model, and Zheng et al. (2003) and Yu and Li (2014) employ ARDL framework and estimate price elasticities for residential electricity. This paper estimates both partial adjustment model and ARDL model, but reports only the results of the partial adjustment model because of low statistical significance of the results from the ARDL model.[4)]

There are also papers to analyze the improvement of technical efficiency in electricity consumption as well as economic growth over time (Bernstein and Griffin, 2005; Lijesen, 2007; Okajima and Okajima, 2013). Bernstein and Griffin (2005) shows that the overall demand for energy increases despite efficiency improvement. Okajima and Okajima (2013) shows the existence of the rebound effect where energy consumption gradually increases over time. This paper also investigates the rebound effect which affects demand for electricity.

We examine the elasticity of demand for electricity in China focusing on the following four aspects: (i) we estimate the determinants of electricity demand of urban residents based on economic factors and a time factor, (ii) we use panel data of urban residential electricity at various regional levels, (iii) FD GMM (First

4) When the national panel data were used for estimation, the results from the ARDL model are similar to the partial adjustment model. When the regional panel data were used based on income and temperature, however, the ARDL estimates show low statistical significance and thus this paper does not report the results of ARDL model. The reason for low statistical significance of the ARDL estimates could be relatively small sample size in our estimation. As mentioned in Okajima and Okajima (2013), the ARDL tends to perform poorly with small sample size.

Difference GMM) approach with IV method is used to avoid the endogenous problem, and (iv) a partial adjustment model is employed to derive the short-run and long-run effects of changes in price and income. As far as we know, there is no paper that estimates electricity demand in China with all of these four characteristics.5)

The remainder of the paper is organized as follows. The next section describes the model specification and data; section 3 discusses the results of the FD GMM with fixed effects; section 4 provides concluding remarks.

Ⅱ. Model Specification and Data

2.1. Model Specification

We study demand for urban residential electricity and estimate its determining factors. A representative consumer maximizes its utility by allocating his/her income to electricity consumption and other goods. The consumer's budget constraint is as follows.

$$P_{i,t}C_{i,t} + P_{xi,t}X_{i,t} \leq I_{i.t} \quad (1)$$

Here i indicates a city, and t represents the year. $P_{i,t}$ is the price of electricity in city i at time t, $C_{i,t}$ is per capita electricity consumption,

5) Our approach is similar to Okajima and Okajima (2013) which estimates electricity demand in Japan. Keum et al. (2018) also used the FD GMM method for Korean data, but it does not divide the regions based on income and temperature levels.

$P_{xi,t}$ is the price index of the other goods, $X_{i,t}$ is per capita consumption in other goods, and $I_{i,t}$ is per capita income. Therefore, the consumer considers the price of electricity, income and other goods to make decision for electricity consumption. The most common econometric model for residential electricity demand takes the form of logarithmic model derived from the Cobb-Douglas utility function. The econometric model takes the following form.[6)]

$$\ln C_{i,t} = \alpha + \beta \ln P_{i,t} + \gamma \ln I_{i,t} + \phi \ln T + u_{i,t} \tag{2}$$

Here $\ln$ is the natural logarithm, T is the time trend, and $u_{i,t}$ is an error term.

This paper considers a partial adjustment model which includes a lagged dependent variable in the regression. This model assumes that the change in log actual demand between any two periods, t and $t-1$, is a fraction of the change between the logarithms of the equilibrium demand in period t and actual demand in period $t-1$ (e.g., Alberini and Filippini, 2011). Formally, actual consumption takes the following form.

$$\ln C_{i,t} - \ln C_{i,t-1} = \lambda(\ln C^{*}_{i.t} - \ln C_{i,t}) \tag{3}$$

Here the adjustment coefficient $0 < \lambda < 1$, and $C^{*}_{i,t}$ is the equilibrium demand. This implies that given an optimum level of electricity demand, the actual demand gradually converges toward the optimum level with the speed of λ. Substituting (2) into equation (3), we obtain a partial adjustment model as follows.

$$\ln C_{i,t} = \alpha + \beta \ln P_{i,t} + \gamma \ln I_{i,t} + \delta \ln C_{i,t-1} + \phi \ln T + u_{i,t} \tag{4}$$

6) In equation (2), the consumption of electricity is the equilibrium amount of electricity.

Using the FD GMM method, equation (4) becomes the following econometric model.

$$\Delta \ln C_{i,t} = \alpha + \beta\Delta\ln P_{i,t} + \gamma\Delta\ln I_{i,t} + \delta\Delta\ln C_{i,t-1} + \phi\Delta\ln T + u_{i,t} \qquad (5)$$

Here Δ is the first difference operator.

The dependent variable in our analysis is urban residential electricity consumption per capita. We include four independent variables. The first independent variable is the urban residential electricity price. We can expect consumers to have two kinds of reaction to increasing electricity prices. In the short-run, the residents reduce the electricity consumption by adjusting the use of current home appliances. In the long-run, the residents respond to relative price changes by purchasing more energy efficient electric appliances as well as by reducing the use of home appliances. According to the equation (5), the short-run price elasticity is represented by β and the long-run price elasticity is $\beta/(1-\delta)$.

The second independent variable is per capita income of urban residents in each city. Electricity appliances such as air conditioner, electric heater and electric cooker have been used widely with increasing income. High income families can increase purchase of electrical equipment and thus high income is expected to cause an increase in electricity consumption.

The third independent variable is the lagged consumption variable. It is added to capture the long-run effect of changes in price and income in a partial adjustment model. Since the lagged dependent variable in the estimation causes the endogenous problem, GMM with IV is used to avoid the problem.

The fourth independent variable is the time variable as in Lijesen (2007). $\Delta \ln T$ is positive but decreasing over time. It is included to check whether the rebound effect exists. The rebound effect indicates increasing electricity consumption as time passes even though the improvement of energy efficiency could lead less consumption of electricity.

We also considered heating degree days, cooling degree days, and index of aging of household. But these variables are not statistically significant in estimation of equation (5). Thus, these variables were removed to improve the estimation results.

2.2. Data

To estimate the Chinese residential electricity demand, we collect annual electricity consumption data of 50 representative cities in China from 2001 to 2011. The 50 cities are from the 4 municipalities and the 46 representative cities in 21 provinces and five autonomous regions.

Per capita electricity consumption and per capita real income of urban residents were obtained from Life and Price Yearbook of Chinese Cities (Towns). The prices of electricity are the consumer price indices of electricity, which were obtained from the China Statistical Yearbook.[7] The price indices of electricity were calculated based on 2000 as the base year. Descriptive statistics are provided in (Table 1).

<Table 1> Descriptive Statistics

Variable	Mean	Stan. Deviation	Minimum	Maximum	No of obs.
Consumption (kWh)	643.34	460.66	97.16	3,468.08	550
Price (Index)	104.86	3.78	92.2	117.6	550
Income (Yuan)	14,164	6,607	4,742	36,505	550

7) The electricity price data are average prices. There are several studies (Taylor, 1975; Acton et al., 1976; Reiss and White, 2005) that set up the block pricing as a marginal price. However, Brown et al. (1975) and Shin (1985) showed no difference between the analysis using the average price and the analysis using the marginal price, since the household generally do not have much information on structural of the price.

When we estimate the urban residential electricity demand function at the national level, we may overlook some important effects that are specific to individual characteristics of different regions. The cities in China are substantially different in development levels and in climates, which results in substantial variations in electricity demand. Therefore, it is necessary to classify cities based on their regional characteristics. To incorporate regional differences, we group the regions based on income and weather.

To analyze the effect of income levels on electricity consumption behavior, we group the 17 cities with the highest mean income as the high income region, the 16 cities with the lowest mean income as the low income region, and the remaining 17 cities as the middle income region (Table 2).[8] Descriptive statistics are provided in (Table 3). We find that high income region records the highest electricity consumption, but the prices are similar among regions. The electricity consumption in low income region is the lowest among the three regional groups.

<Table 2> Regions based on Income

Group	Cities
High income	Beijing, Changsha, Fuzhou, Guangzhou, Nanjing, Jinan, Shanghai, Tianjin, Hangzhou, Dalian, Qingdao, Shenzhen, Wenzhou, Xiamen, Weihai, Suzhou, Chengdu
Middle income	Hefei, Chongqing, Shijiazhuang, Harbin, Zhengzhou, Wuhan, Huhhot, Zhuzhou, Xuzhou, Luoyang, Langfang, Nanning, Shenyang, Nanchang, Changchun, Xi'an, Taiyuan
Low income	Lanzhou, Guiyang, Yinchuan, Xining, Urumqi, Kunming, Yichang, Sanya, Qiqihar, Kaifeng, Jilin, Baoji, Datong, Ganzhou, Huangshan, Haikou

8) As in Okajima and Okajima (2013), the three regions are divided by the mean of income.

<Table 3> Descriptive Statistics of the Regions based on Income

Variable	Region	Mean	Stan. Dev.	Minimum	Maximum	No of obs.
Consumption (kWh)	High income	964.74	613.733	234	3468.08	187
	Middle income	499.55	181.27	170.69	1055.68	187
	Low income	454.62	246.35	97.16	1580.32	176
Price (Index)	High income	103.98	3.75	92.2	112.5	187
	Middle income	105.30	3.54	93.3	116.1	187
	Low income	105.32	3.89	92.6	117.6	176
Income (Yuan)	High income	18607.26	7435.67	7418	36505	187
	Middle income	12916.06	5036.98	5770	28110	187
	Low income	10767.83	4068.58	4742	22337	176

We also categorize cities based on temperature. The 17 cities with the highest temperature are grouped as the hot region; the 16 cities with the lowest temperature are grouped as the cold region; and the other 17 cities as the mild region (Table 4).[9] Descriptive statistics are provided in Table 5. We find that the hot region records the highest income and the highest electricity consumption. But the price of electricity in the hot region is the lowest. The cold region is characterized as the lowest income and the lowest electricity consumption.

<Table 4> Regions based on Temperature

Group	Cities
Hot	Chongqing, Fuzhou, Guangzhou, Nanning, Haikou, Changsha, Nanchang, Shanghai, Nanjing, Hangzhou, Sanya, Shenzhen, Xiamen, Wenzhou, Ganzhou, Zhuzhou, Yichang
Mild	Hefei, Guiyang, Shijiazhuang, Zhengzhou, Wuhan, Kunming, Jinan, Xi’an, Taiyuan, Chengdu, Luoyang, Huangshan, Xuzhou, Suzhou, Kaifeng, Qingdao, Weihai
Cold	Beijing, Lanzhou, Urumqi, Harbin, Changchun, Shenyang, Huhhot, Yinchuan, Xining, Tianjin, Qiqihar, Jilin, Dalian, Langfang, Datong, Baoji

9) As in Okajima and Okajima (2013), the three regions are divided by the mean of temperature.

<Table 5> Descriptive Statistics of Regions based on Temperature

Variable	Region	Mean	Stan. Dev.	Minimum	Maximum	No of obs.
Consumption (kWh)	Hot	851.43	667.36	97.16	3468.08	187
	Mild	583.66	283.25	119.88	1580.32	187
	Cold	485.65	173.30	164.53	1104.25	176
Price (Index)	Hot	103.72	4.15	92.2	112	187
	Mild	105.14	3.40	97	116.1	187
	Cold	105.76	3.41	98.6	117.6	176
Income (Yuan)	Hot	16274.65	7561.78	5304	36505	187
	Mild	13520.47	5761.60	5383	34617	187
	Cold	12604.04	5726.10	4742	34669.8	176

Ⅲ. Empirical Results

3.1. Results from National Panel Data

This paper uses a partial adjustment model which includes a lagged dependent variable in the regression. The presence of such a lagged dependent variable causes endogenous problem which generates the dynamic panel bias (Cameron and Trivedi, 2009). If the dynamic panel bias exists, we cannot trust long-run price elasticity because it makes the coefficient of the lagged dependent variable also biased. In order to avoid the dynamic panel bias, the FD GMM can be used. The FD GMM takes first differences to eliminate the individual effects and uses lagged levels as instruments.

We test if the dependent variable is unit root.[10] Since the properties of GMM estimators are sensitive to the choice of instruments, we test unit root before choosing between the FD GMM and the SY (system) GMM. One condition for the FD GMM is that the dependent variable has no unit root property.[11] Otherwise we might instead use the SY GMM, which was proposed by Blundell and Bond (1998). The result of unit root test is shown in Table 6. The dependent variable (lnC) does not have a unit root, which indicates that the FD GMM is appropriate for our data.[12] Therefore, we use the FD GMM with the fixed panel analysis

10) Robustness of the unit root test result was verified by using both IPS and Pesaran methods.

11) The FD GMM estimator suffers from the weak instrument probloem if the dependent variable has a near unit property. (Okajima and Okajima, 2013, p. 436)

12) As for the method of using the system GMM and the FD GMM in estimating electricity

where differencing eliminates the combined fixed effects. When we check for the unit root with regional data based on income and temperature, we also reject the null hypothesis of unit root in all variables in the estimation.

<Table 6> Results from Unit Root Test

Variable	Statistic	p-value
$\ln C$	-4.2115	0.0000
$\ln P$	-9.6653	0.0000
$\ln I$	-5.2588	0.0000
$\Delta \ln C$	-11.2368	0.0000
$\Delta \ln P$	-12.8022	0.0000
$\Delta \ln I$	-11.7076	0.0000

Note: Results from IPS

We also run the over-identification test for the instrument variable in the first stage estimation. To apply the FD GMM method, we use the Sargan test to check for over-identifying restrictions. Under the null hypothesis that all instruments are valid, it can be shown that we cannot reject the null hypothesis because the p-value is greater than 0.05 as shown in Table 7. When we apply the Sargan test for regional panel data based on income and temperature, we also cannot reject the null hypothesis.

<Table 7> Results from Sargan Test of Over-identifying Restrictions

H0: Over-identifying restrictions are valid.	
χ^2	45.2835
P-Value	0.4182

demand, refer to Okajima and Okajima (2013), pp. 434-435.

Table 8 summarizes the estimation results of the regression with the national panel data. The coefficients of price and income are negative and positive, respectively. The number of cities used in the regression are 50 and the total observations in the panel analysis are 450.

<Table 8> Estimation Results from the National Panel Data

	$\Delta \ln C_{i,t-1}$	$\Delta \ln P_{i,t}$	$\Delta \ln I_{i,t}$	$\Delta \ln T_t$	Constant
Coefficient	0.0283***	-0.5052***	0.5108***	0.1145***	3.4590***
	(0.003)	(0.025)	(0.010)	(0.005)	(0.179)

Note: 1) Standard errors are given in parentheses.
2) *** indicates statically significance at 1% level.

The estimated coefficients of price and income shown in Table 8 are short-run elasticities of urban residential electricity demand in China. Using the coefficient of lagged consumption, we can calculate long-run elasticities of electricity demand which are reported in Table 9. The long-run price elasticity at national level is -0.5199, while the short-run elasticity is -0.5052. The negative value of price elasticities is consistent with the law of demand, which indicates that when electricity price increases, electricity consumption declines. The long-run price elasticity is greater than the short-run price elasticity as in Shen (2011). As for the income elasticity, the long-run elasticity is 0.5257 and short-run elasticity is 0.5108. Since the electricity consumption increases with income and the elasticity is less than one, electricity is a necessity good.

<Table 9> Elasticities of Residential Electricity Demand

	Short-run elasticity	Long-run elasticity
Price elasticity	-0.5052	-0.5199
Income elasticity	0.5108	0.5257

The coefficient of $\Delta \ln T$ shown in Table 8 is 0.1145, which means that electricity consumption increases with time. This indicates the possible existence of the rebound effect in China. While efficiency improvement reduces electricity consumption, technical progress or economic growth make electricity consumption increase.[13)]

3.2. Results from Regional Panel Data based on Income

We categorize the cities based on income levels because electricity consumption behavior may be different depending on income levels. As argued in Holtedahl and Joutz (2004), electricity consumption and urbanization are considered to be an indicator of economic development. For example, more wealthy people would buy more home appliances to improve the quality of life, which makes the people consume more electricity. Table 10 shows the estimation results from the regression based on income levels by using the partial adjustment model. The coefficients of price, income, and time variables are negative, positive, and positive, respectively.

13) As in Okajiman and Okajiman (2013), the positive coefficient of $\Delta \ln T$ indicates existence of the rebound effect. However, the coefficient estimate of a time trend variable does not provide any specific mechanism of the rebound effect, we need to be careful in interpreting the sign of the time trend coefficient as an evidence of the rebound effect.

<Table 10> Estimation Results from the Regional Panel Data based on Income

	High income	Middle income	Low income
$\Delta \ln C_{i,t-1}$	0.1196***	0.3388***	0.3090***
	(0.024)	(0.096)	(0.036)
$\Delta \ln P_{i,t}$	-0.2489**	-0.2863*	-0.6173***
	(0.103)	(0.172)	(0.113)
$\Delta \ln I_{i,t}$	0.3635***	0.2052***	0.3053***
	(0.059)	(0.044)	(0.085)
$\Delta \ln T_t$	0.1734***	0.1306***	0.1240***
	(0.026)	(0.049)	(0.031)
Constant	3.3301***	3.2672**	4.0191***
	(0.367)	(1.275)	(0.974)
Number of Observations	153	153	144
Number of Cities	17	17	16

Note: 1) Standard errors are given in parentheses.
2) Statistcally significant at 1% (***), 5% (**) or 10% (*)

The results of the price and income elasticities in different income regions are shown in Table 11. The short-run price elasticities are -0.6173 in the low income region, -0.2863 in the middle income region, and -0.2489 in the high income region, which shows decreasing elasticity in absolute values with increasing income level. That is, electricity consumption is more sensitive to price changes in low income region than in high income region.[14] Long-run price elasticities show similar pattern as in the short-run, but the elasticities in the long-run are greater than in the short-run.

14) This is different from Okajima and Okajima (2013) where electricity consumption is the most sensitive in high income region in Japan. It is probably caused by more tight budget constraint of low income people in China compared to Japan.

<Table 11> Elasticities of Electricity Demand in Different Income Regions

	Short-run elasticity	Long-run elasticity
Price elasticity		
High income	-0.2489	-0.2827
Middle income	-0.2863	-0.4330
Low income	-0.6173	-0.8933
Income elasticity		
High income	0.3635	0.4129
Middle income	0.2052	0.3103
Low income	0.3053	0.4418

Electricity is inelastic to price changes since the absolute values of price elasticity are less than one in all three regions. As Chinese economy grows, the demand for electricity will increase with income. An increase in electricity price may be used to control electricity demand. However, the effect of price increase will be lessened as income increases. High-income households are relatively less sensitive to changes in electricity prices. Thus, Chinese policy for electricity should consider the less effectiveness of higher price policy on electricity demand as income increases in the future.

The income elasticities in all three regions are less than one, which indicates that electricity is a necessity good. This result is different from Lin et al. (2014) where income elasticity of electricity demand is estimated to be higher than one. The size of income elasticity follows a V-shape as regional income level increases. It is interesting that the income elasticities in the low income region and the high income region are higher than in the middle income region. This result indicates that when income increases, the people in the low and high income regions increase the purchase of electric appliances more rapidly and consume more electricity than in the middle income region.

In the short run, the income elasticity in the high income region is greater than in other regions. The income elasticities in all three regions are greater in the long run than in the short run. These results imply that the demand for electricity will increase at a higher speed in the future and the government needs to prepare for the rapid increase of the electricity demand as Chinese economy continues to grow.

When we combine the price elasticity and income elasticity by adding the two short-run elasticities for each region, the value increases as the region moves from the low income region to the high income region. As shown in Table 12, it is -0.3120 for the low income region, -0.0811 for the middle income region, and 0.1146 for the high income region. Thus, when both the price and income increase at the same rate, the net change in electricity consumption is greater in the high income region than in other regions. This result implies that when more regions are moving from the low income region to the high income region as Chinese income grows, the increase of price electricity will be less effective as a tool to control the demand for electricity because of the increasing income effect. Moreover, as shown in Table 12, the regional difference in the long-run elasticity is greater than that in the short-run elasticity.

<Table 12> Sum of Income and Price Elasticities

	Short-run	Long-run
High income	0.1146	0.1302
Middle income	-0.0811	-0.1227
Low income	-0.3120	-0.4515

The coefficients of $\Delta \ln T$ are positive for the three regions. It indicates the existence of the rebound effect in all three regions. The effect of technical progress or economic growth on electricity consumption may be greater than the effect of efficiency improvement in residential use of electricity consumption in China.

3.3. Results from Regional Panel Data based on Temperature

We classify the cities based on temperature such as hot, mild and cold regions since urban residential electricity consumption varies with temperature in the region. Table 5 shows that the average electricity consumption in the cold region is the lowest while it is the highest in the hot region. Electricity consumption might be lower in cold regions because the residents use coal for heating or have central heating from gas. Table 13 shows the results of the regressions for hot, mild, and cold regions.

<Table 13> Estimation Results from the Regional Panel Data based on Temperature

	Hot	Mild	Cold
$\Delta \ln C_{i,t-1}$	0.2661***	0.3105***	0.2471
	(0.031)	(0.031)	(0.166)
$\Delta \ln P_{i,t}$	-0.3563***	-0.4301***	-0.2426
	(0.046)	(0.161)	(0.279)
$\Delta \ln I_{i,t}$	0.3552***	0.3016***	0.3842***
	(0.054)	(0.052)	(0.130)
$\Delta \ln T_t$	0.1278***	0.1463***	0.0002
	(0.040)	(0.033)	(0.049)
Constant	2.8658***	3.2470***	2.1422
	(0.523)	(0.826)	(1.746)
Number of Observations	153	153	144
Number of Cities	17	17	16

Note: 1) Standard errors are given in parentheses.
2) Statistcally significant at 1% (***), 5% (**) or 10% (*)

From the partial adjustment model, electricity consumption in the mild region is the most elastic to price changes, which makes an inverse

V-shape in the short run as regional temperature moves from cold to hot. As shown in Table 14, the shape of long-run elasticity is the same as the short-run elasticity. The higher price elasticity in mild region might be explained by the possibility of changes in using air conditioner or other electric appliances than in hot and cold regions. When electricity price increases, the residents in mild regions might easily choose to decrease the use of electrical heating in winter or reduce the use of air conditioning in summer. The responsiveness to electricity price changes is the lowest in the cold region. It may be caused by the difficulty in reducing electric heating in cold winter.[15)]

The coefficients of income from our estimation are 0.3552 in the hot region, 0.3016 in the mild region, and 0.3842 in the cold region, which has a V-shape as regional temperature increases. Electricity consumption in cold and hot regions responds more strongly to an income change. It implies that as income increases, the people in cold and hot regions consume more electricity than in the middle income region. This may be explained by more need for using electrical appliances in hot and cold regions, and as income increases, households in these regions respond with more use of electricity.

The coefficients of $\Delta \ln T$ are still positive for all of the three regions. This again indicates the dominant effect of economic growth on electricity consumption over efficiency improvement with time.

15) According to Okajima and Okajima (2013), it is the cold region that is the most elastic to price changes in Japan. The cold region in China may not be very sensitive to price changes because electricity is not the main source of heating in winter and air conditioner is not broadly used in summer.

<Table 14> Elasticities of Electricity Demand in Different Temperature Regions

	Short-run elasticity	Long-run elasticity
Price elasticity		
Hot region	-0.3563	-0.4855
Mild region	-0.4301	-0.6238
Cold region	-0.2426	-0.3222
Income elasticity		
Hot region	0.3552	0.4840
Mild region	0.3016	0.4374
Cold region	0.3842	0.5103

Ⅳ. Conclusion

This paper estimates urban residential electricity demand functions of six regional groups in China based on different income and temperature levels. We utilize a partial adjustment model with FD GMM method. The main results can be summarized as follows.

First, electricity consumption decreases as price increases as expected, but the degree of price elasticity is dependent on regional income and temperature. Households in the regions of low income and mild temperature are more sensitive to the changes in electricity price. This can be explained by household budget constraint and flexibility in selecting home appliances. The estimated short-run price elasticity decreases with income. Electricity consumption is the most sensitive to price changes in the low income region. Tight budget constraint in the low income region could be the reason for high price elasticity. As for the regional temperature, electricity consumption in the mild region is most elastic to electricity prices. Higher elasticity in the mild region might be explained by higher flexibility in using air conditioner or other electric appliances compared to other regions. Long-run price elasticity is greater than short-run price elasticity, which is typically observed in the literature.

Second, electricity consumption increases with income as expected, but the degree of elasticity is different depending on regional income and temperature. Households in the regions of high income and cold temperature are more sensitive to the changes in income. As income increases, the residents in the high income region appear to buy more electric appliances and consume more electricity. Electric heating and cooling are relatively expensive in China, so it may be in the high income region that people buy more electric appliances and consume more electricity when income increases. Electricity consumption in the cold region responds most strongly to income changes. It implies that the people in the cold region consume more electricity as income increases. The reason might be that in the cold region, more people begin to change the heating system from coal fire heating to electric heating as income increases.

Third, electricity consumption increases as time passes, which indicates the possible existence of the rebound effect. While efficiency improvement reduces electricity consumption with time, technical progress or economic growth stimulates electricity consumption. Our results indicate that the increasing effect of technical progress or economic growth is greater than the effect of efficiency improvement.

Fourth, as a policy implication, Chinese government need to consider the possibility of less effectiveness of higher price policy on electricity demand as Chinese economy grows. Chinese government may need to increase the price of electricity to control increasing electricity consumption followed by economic growth. However, the effect of price increase will be lessened as income increases, which is implied by the smaller price elasticity in the high income region in our estimation results.

Our study focuses on price, income and temperature as the main determinants of electricity consumption in China. The variables such as heating degree days, cooling degree days, and index of aging of household are not included in our estimation because of low statistical significance. For further understanding of energy consumption in China, we may need to analyze the reasons for low relationship between electricity consumption and those variables in China. Other potential factors might be population growth, price of alternative energy sources and family size. These factors may need to be considered for more comprehensive understanding of electricity demand in China.

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◎ Reference ◎

Ahn, S., Jin, S., Yoo, S. 2016. "Estimation of the electricity demand function using a lagged dependent variable model." *Journal of Energy Engineering* 25(2) : 37-44. (in Korean)

Alberini, A. and Filippini, M. 2011. "Response of residential electricity demand to price: the effect of measurement error." *Energy Economics* 33 : 889–895.

Arellano, M. and Bond, S. 1991. "Some tests of specification for panel data: Monte Carlo evidence and an application to employment equations." *Review of Economic Studies* 58 : 277-297.

Beenstock, M., Goldin, E. and Nabot, D. 1999. "The demand for electricity in Israel." *Energy Economics* 21 : 168-183.

Bernstein, M. and Griffin, J. 2005. *Regional Differences in the Price-elasticity of Demand for Energy.* (Santa Monica, California: RAND Corporation)

Blundell, R. and Bond, S. 1998. "Initial conditions and moment restrictions in dynamic panel data models." *Journal of Econometrics* 87 : 115-143.

Cameron, C. A. and Trivedi, P. K.. 2009. *Microeconometrics Using Stata.* (College Station: Stata Press)

Dergiades, T. and Tsoulfidis, L. 2008. "Estimating residential demand for electricity in the United States, 1965–2006." *Energy Economics* 30 : 2722-2730.

Dong, J. and Wu, M. 2011. "Cointegration study of influencing factor of residential electricity consumption in China," *Water Resources and Power* 9 : 185-187. (in Chinese)

Halicioglu, F. 2007. "Residential electricity demand dynamics in Turkey." *Energy Economics* 29 : 199-210.

Harrison F., Shanjun, L. and Paul, A. 2010. "A new look at residential electricity demand using household expenditure data." *RFF Discussion paper.* 10–57. Washington, DC, October.

Hondroyiannis, G. 2004. "Estimating residential demand for electricity in Greece." *Energy Economics* 26 : 319-334.

Holtedahl, P. and Joutz, F. L. 2004. "Residential electricity demand in Taiwan." *Energy Economics* 26: 201-204.

Judson, R. and Owen, A. 1999. “Estimating dynamic panel data models: a guide for macroeconomists.” *Economics Letters* 65 : 9-15.

Keum, Yejin, O-Sung Kwon and Young Wan Goo. 2018. "Estimation of residential electricity demand in Korea: by using dynamic panel GMM model." *Korean Energy Economic Review* 17(1) : 37-65. (in Korean)

Li, H., Wang, B. Guo, S. and Su, C. 2012. “Driving factors of inter-provincial difference in China’s power tariff and its scenario simulation.” *East China Electric Power* : 1001-9529 11-1872-05. (in Chinese)

Lijesen, M. G. 2007. “The real-time price elasticity of electricity.” *Energy Economics* 29 : 249-258

Lin, Q., Rizov, M. and Wong, M. 2014. “Residential electricity pricing in China.” *Chinese Economy* 47(2) : 41-74.

Matsukawa, I., Madono, S. and Nakashima, T. 1993. “An empirical analysis of Ramsey pricing in Japanese electric utilities.” *Journal of the Japanese and International Economies* 7 : 256-276.

Mizobuchi, K. 2008. “An empirical study on the rebound effect considering capital costs.” *Energy Economics* 30 (5) : 2486-2516.

Nakajima, T. 2010. “The residential demand for electricity in Japan: an examination using empirical panel analysis techniques.” *Journal of Asian Economy* 21 : 412-420.

Nakajima, T. and Hamori, S. 2010. “Change in consumer sensitivity to electricity prices in response to retail deregulation: a panel empirical analysis of the residential demand for electricity in the United States.” *Energy Policy* 38 (5) : 2470-2476.

Narayan, P. K. and Smyth, R. 2005. “The residential demand for electricity in Australia: an application of the bounds testing approach to cointegration.” *Energy Policy* 33(4) : 476-474.

Narayan, P. K., Smyth, R. and Prasad, A. 2007. “Electricity consumption in G7 countries: A panel cointegration analysis of residential demand elasticities.” *Energy Policy* 35(9) : 4485-4494.

Okajima, S. and Okajima, H. 2013. “Estimation of Japanese price elasticities of residential electricity demand, 1990–2007.” *Energy Economics* 40 : 433-440.

Paul, A., Myers, E., and Palmer, K. 2009. “A partial adjustment model of U.S. electricity demand by region, season, and sector”, Resource for the Future Discussion Paper.

Shen, X. 2011. *The Elastisities of Electricity Demand in Urban Households: Based on Zhejiang Provincial empirical research.* Zhejiang University. (in Chinese)

Shen, X. 2014. “Influencing factors on rural residential electricity demand in China.” *Statistical Research* 34(1) : 84-90. (in Chinese)

Yu, Y. and Li, H. 2014. "The elastisities of residential electricity demand in China." *Productivity Research* 11. (in Chinese)

Zheng, H., Zhang, A. and He, J., 2003. "Beijing residential electricity consumption analysis." *Journal of Tsinghua University* (Science and Technology) 43(6). (in Chinese)

Ziramba, E. 2008. "The demand for residential electricity in South Africa." *Energy Policy* 36(9) : 3460-3466.

요 약

가정용 전기소비 결정요인: 중국의 소득과 온도 수준에 따라 분석

구영완 *, 김승연 **, 장선(Zhang Chan) ***

이 논문은 소득과 기온을 기준으로 중국을 세 그룹으로 구분하여 패널 FD GMM을 사용하여 도시 거주용 전기 수요를 추정하였다. 실증 분석 결과는 다음과 같다. 첫째, 전력 가격이 높을수록 전기 소비량이 감소하며, 전기에 대한 수요의 가격 탄력성은 단기보다 장기에 더 크게 나타났다. 가격 탄력성은 저소득 지역과 온난 한 지역에서 가장 크게 나타났다. 둘째, 소득 증가로 전기 소비가 증가했다. 단기적으로 고소득 지역과 추운 지역의 소득 탄력성은 다른 지역보다 높게 나타났으며, 장기에 더 민감한 것으로 나타났다. 셋째, 시간이 지남에 따라 전력 소비가 증가하는 리바운드 효과가 나타났다. 이는 경제 성장이 전력 소비에 미치는 영향이 시간이 지남에 따른 에너지 효율 개선 효과보다 높다는 것을 보여준다. 넷째, 전력 소비를 통제하는 정부의 정책은 소득이 증가함에 따라 가격 탄력성을 감소시키는 것을 고려해야한다.

주요 단어 : 전기 수요, FD GMM, 소득 탄력성, 가격 탄력성, 반등 효과

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