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Elasticities of residential electricity demand in China under increasing-block pricing constraint: New estimation using household survey data

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ABSTRACT

China has implemented the residential increasing-block electricity pricing (IBEP) policy since the second half of 2012, which is considered the most effective economic instrument in improving residential energy efficiency. Price and income elasticity are two fundamental parameters to guide both scholars and policy-makers in assessing whether and to what extend Chinese households respond to the policy. However, it presents the challenge of simultaneous determination of marginal price and electricity consumption; further, it is less examined from an empirical perspective due to the absence of micro-level data. To fill this gap, this study estimates price and income elasticity by establishing two instrumental variables, based on a unique dataset from the Chinese Residential Energy Consumption Survey 2014. Results show that the residential demand for electricity is price inelastic and that electricity is an essential commodity for households in the short run. It also shows great urban-rural disparity and regional heterogeneity of household electricity consumption behavior regarding short-run income elasticity. The estimated parameters of short-run price and income elasticities provide a valuable reference for policy-making regarding both a nationwide uniform and a differential regional perspective.

1. Introduction

Estimating the price and income elasticity of household electricity demand is a fundamental task for economic analysis and public policy. These elasticities constitute pivotal indicators for academic scholars to validate the economic theory in various practical scenarios, characterize residential electricity consumption behavior, and be applied in the complex integrated computable general equilibrium (CGE) model for calibration purposes. As for policy-makers, it is a key probe to assess the effectiveness of various electricity-saving intervention measures, and form the scientific basis for enacting practicable demand-side management policy.

While elasticity is of great importance in economic theory and practice, the existing literature has several limitations. First, the countries of research in previous studies are imbalanced. Abundant studies that estimate price elasticity and income elasticity of residential electricity demand have been conducted for developed countries such as the United States (Reiss and White, 2005; Paul et al., 2009; Alberini and Filippini, 2011; Alberini et al., 2011), European countries (Berkhout et al., 2004; Filippini, 2011; Blázquez et al., 2013), and other high-income economies (Ang et al., 1992; Beenstock et al., 1999; Sa'ad, 2009; Nakajima, 2010; Hung and Huang, 2015). However, it is now acknowledged that developing countries play an increasingly important role in world energy consumption (Wei et al., 2020). Consider the largest developing countries, China and India, as examples: the residential electricity consumption in these two countries reached about 2500 TWh in 2018, accounting for 10.2% of global demand (Central Electricity Authority of India, 2019; National Bureau of Statistics of China, 2019; British Petroleum, 2020). A global picture of household electricity demand absenting these fast-switching new actors is not representative and incomplete. Second, the literature fails to reach a consistent estimation. The previous estimated results vary greatly due to variations in the data used, the time span, and the selected econometric models. For example, in line with experience and theory, household

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electricity use is a normal good that is expected to have a positive income elasticity. However, some empirical studies evidenced zero or even negative income elasticity (Reiss and White, 2005; Filippini, 2011). Recently, it is argued that elasticity estimation may suffer the endogenous problem challenge (Reiss and White, 2005). For example, when a household faces an increasing-block electricity tariff, the more electricity the household consumes, the higher the marginal electricity price that it would be charged. This brings about the issue of simultaneous determination of marginal price and electricity consumption. Ignoring the problem may lead to biased price and income elasticity estimates (Hung and Huang, 2015).

This paper presents a new and robust estimation of China's residential electricity demand's price and income elasticities by including established instrumental variables based on representative household survey data. Three reasons motive our work. **First**, China's household electricity demand is of great practical significance in terms of its scale and growth rate. The last 25 years have witnessed substantial growth in residential electricity demand, from about 90 TWh in 1994 to almost 1000 TWh in 2018, with an annual growth rate of 10.6% (National Bureau of Statistics of China, 2019). It is estimated that, driven by the ongoing rapid urbanization process and the continuous improvement in residents' quality of life, this number is bound to escalate as high as 1112 TWh by 2025 (Cao et al., 2019). Understanding the electricity demand pattern is crucial to policy-makers. **Second**, due to data unavailability, studies in mainland China have been sparse. Sun and Lin (2013) used aggregated yearly data of 30 provinces to study price and income responses to residential electricity demand. They found that more affluent consumers were less sensitive to price changes. Zhou and Teng (2013) found that the residential electricity demand was price- and income-inelastic, based on urban household data in Sichuan province. Cao et al. (2016) and Cao et al. (2019) used cross-sectional Chinese Urban Household Survey data from 2002 to 2009 and obtained similar conclusions. These few exploratory studies provide valuable benchmark estimations. However, previous estimations may not be appropriate to the present situation since the policy has been substantially updated. A fundamental change is the electricity price policy. Prior to the second half of 2012, the residential electricity tariff was almost fixed over the years. Since the second half of 2012, China began to implement the nationwide residential increasing-block electricity pricing (IBEP hereafter) policy. According to economic theory, the price change is expected to affect electricity demand negatively. **Third**, the potential heterogeneity in electricity consumption behavior among different areas is not accounted for in the literature. For example, the representative urban residents' per capita disposable income is nearly three times higher than for rural residents; further, the income of typical residents in the eastern area is about 1.5–1.7 times higher than that of residents in the middle or western areas (National Bureau of Statistics of China, 2019). These substantial household income differences might significantly affect the stock of electrical appliances and residents' electricity consumption behavior.

Our work differs from previous studies in three aspects. **First**, we use new 2014 household survey data. This novel micro-level data enables us to obtain a new set of elasticity estimations under the IBEP constraint. **Second**, we establish the instrumental variables for the marginal electricity price and annual household income. The instrumental variables are included for elasticity estimation to address the endogenous problem. **Third**, we explore heterogeneity in residential electricity consumption behavior by urban and rural regions and east, middle and west regions.

The rest of the paper is organized as follows. Section 2 briefly introduces the increasing-block pricing policy in China's residential sector. Section 3 presents the data, and Section 4 introduces the estimation strategy, including the steps to obtain instrumental variables and develop the econometric models. Section 5 provides the estimated results, and the conclusions and policy implications are outlined in Section 6.

2. Development of China's residential IBEP policy

Central policy-makers have been designing a cross-subsidy electricity pricing strategy since the 1950s. The residential electricity price has been regulated at a low level with little variation, while the industrial sector undertakes the subsidy burden at a higher level (Lin and Jiang, 2011; Yang et al., 2018). The adjustment frequency and amplitude of the residential electricity price are far lower than that of the industrial sector. During 2001–2014, the average retail residential electricity price increased from 0.46 Yuan per kWh to 0.53 Yuan per kWh, representing an increase of 15.2%. In contrast, the average industrial electricity retail price increased from 0.5 Yuan per kWh to 0.79 Yuan per kWh, representing a higher increase of 58.0% in the same period (Liu and Lin, 2020).

While this low pricing strategy for residential electricity is aimed at benefiting households, it may negatively affect overall efficiency. For example, the lower regulated electricity price fails to encourage households to use electricity in an energy-saving manner (Yu and Wang, 2020). In addition, it creates inequity since households with higher electricity consumption enjoy more subsidies, while households with less consumption enjoy fewer subsidies due to cross-subsidy of prices (Lin and Jiang, 2012).

In order to address these concerns, the IBEP policy was first proposed in 2004 in China. This policy divides electricity consumption into several blocks and sets an incremental marginal rate for each block. In other words, a household will face a different electricity rate when its consumption triggers a pre-set threshold. Prior to nationwide implementation, two provinces (Zhejiang and Fujian) were selected as first-round pilot areas in 2004, followed by the second-round pilot province (Sichuan) in 2006. Based on the pilot experience, together with extensive public consulting and discussion, the National Development and Reform Commission (NDRC) issued *the Guidance on Trial Increasing-block Pricing Policy of Residential Electricity* in November 2011. Two basic principles are used to design a specific IBEP mechanism according to the guidance. First, electricity consumption is divided into three blocks. It is suggested that the first and second blocks cover the electricity consumption of about 80% and 95% of households, respectively. The second principle is to design reasonable and differential electricity rates for three blocks. The rate of the first block is suggested to maintain a low level and remain unchanged in the long term, while the rate of the second block should be priced to cover the reasonable cost of power enterprises and obtain a reasonable revenue; the third block's rate is expected to reflect the cost of environmental damage and encourage electricity saving. It is priced as high as around 1.5 times the rate of the second block.

Based on the general framework and guiding opinions concerning IBEP policy, provincial governments were entitled to enact local programs. Given significant regional disparity in terms of the local physical and geographical environment, economic development level, and residents' income and power consumption level, the provincial IBEP schemes are flexible to accommodate each block's specific electricity consumption and each block rate. Since the second half of 2012, the IBEP policy has been implemented nationwide in China's residential sector. Great disparities exist among provinces' schemes concerning the electricity quantity in each block. Fig. 1 displays the different block settings and block rates of the IBEP policy for China's 29 mainland provinces (Xinjiang and Tibet are excluded due to the absence of the policy).

Some findings are as follows. **First**, the specific electricity consumption in each block is expressed officially in different metering cycles. Specifically, only in Guizhou province, each block's electricity consumption is officially and directly expressed in a yearly standard, namely 0–2200 kWh for the first block, 2201–4000 kWh for the second block, and 4001 kWh and above for the third block. Alternatively, the other 29 provinces or regions release the electricity consumption in each block in monthly standards, such as 0–180 kWh for the first block,

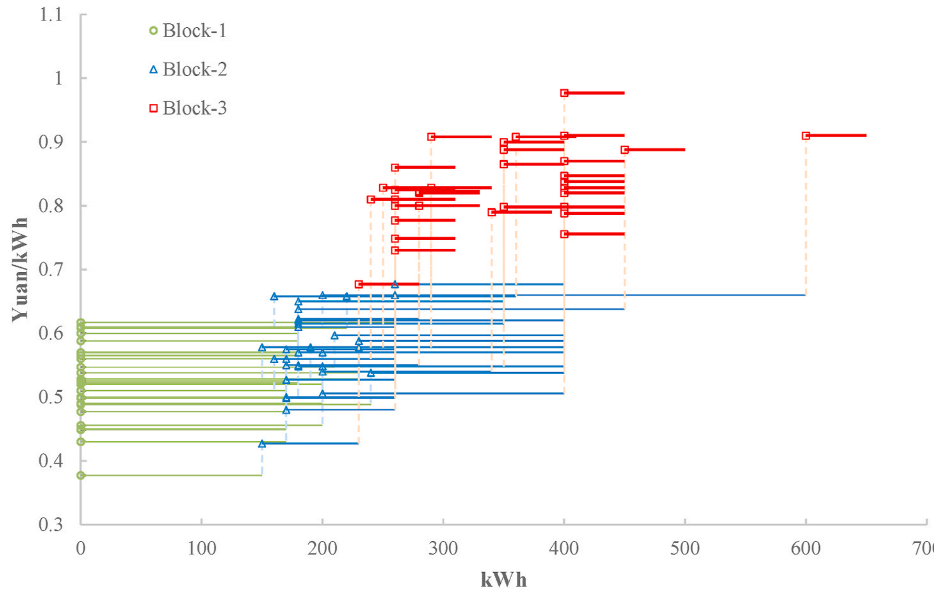

Fig. 1. IBEP scheme for China's provinces.

181–350 kWh for the second block, and 351 kWh and above for the third block in Anhui province.

Second, as a constraint to electricity consumption using a monthly standard, significant differences exist in electricity consumption ranges and block rates among different provinces or regions. For example, consumption within the first block ranges from the lowest level of 150 kWh per month (Qinghai and Guangxi province) to the highest level of 260 kWh per month (Shanghai and Guangdong province). As for the second block, Qinghai registers the lowest upper boundary of 230 kWh per month, while Guangdong has the highest setting of 600 kWh per month.

Third, overall, the third-second block rate gap is greater than that of the second-first block rate gap among provinces. Across all provinces or regions, the first block's average rate is 0.525 Yuan per kWh, with an increase of merely 0.050 Yuan (9.5%) for the second block rate's average at 0.575 Yuan per kWh. In contrast, there is a pronounced larger increase of 0.244 Yuan (42.4%) for the third block's average rate compared with the second block, at 0.819 Yuan per kWh. Among all provinces, Shanghai holds the highest rates for three blocks, that is, 0.617, 0.677, and 0.977 Yuan per kWh, while Qinghai has the lowest rates, namely, 0.377, 0.427, and 0.677 Yuan per kWh.

Fourth, across twelve months in one year, 25 provinces or regions have adopted a uniform IBEP scheme, while five provinces adopted three time-of-use (TOU) pricing schemes in different seasons, based on local weather conditions or the availability of renewable power. Specifically, Guangdong province distinguishes between the summer (from May to October) and non-summer periods (from November to April of the following year). Hainan province distinguishes between the summer (from April to October) and winter periods (from November to March of the following year), since there is almost no spring or fall in this area. Hunan province distinguishes between the spring or fall period (from March to May and September to November) and the summer or winter period (from June to August and December to February of the following year). Further, Guangxi province officially distinguishes between the peak period (from January to February and June to September) and the non-peak period (from March to May and October to December). For the above four provinces, each block's electricity consumption are adjusted in different periods, while each block rate remains unchanged. However, Yunnan province distinguishes months of implementing different electricity pricing schemes based on the availability of hydropower. Namely, the wet season (from May to November), in which all three block rates are set at 0.450 Yuan per kWh, and the non-wet season (from December to April of the following year), in which the three block rates are set at 0.450, 0.500, and 0.800 Yuan per kWh, respectively. Table 1 clusters provinces into four groups, based on the use of a uniform IBEP scheme across one year and the calculation cycle of the electricity bill.

Fifth, two fundamentally different electricity bill calculation cycles are employed, namely, "Monthly" in 11 provinces or regions and "Yearly" in 19 provinces. For a monthly electricity billing cycle, the electricity consumption of a household is metered at a monthly frequency, and the electricity bill for the metered monthly electricity amount is calculated according to the monthly IBEP scheme. By way of example, consider a household in Hubei province that consumes 600 kWh in January. The electricity bill for January is calculated as per the following formula: 180 kWh*0.570 Yuan/kWh + (400–180) kWh*0.620 Yuan/kWh + (600–400) kWh*0.870 Yuan/kWh = 413.00 Yuan. However, for a yearly electricity billing cycle, the electricity bill for the metered monthly electricity amount is calculated based on yearly rather than monthly electricity consumption blocks—even though a household's electricity consumption is metered monthly. As example, consider Anhui province and assume, as for the Hubei example, a household that consumes 600 kWh in January. The January electricity bill is calculated as per the formula: 600 kWh * 0.565 Yuan/kWh = 339.00 Yuan. This is because the cumulative electricity consumption of this household in that year (600 kWh) is still within the first yearly block of electricity consumption (180 kWh/month * 12 months/

Table 1
Four types of IBEP schemes by bill circle.

Type	Having uniform IBEP scheme across one year or not	Calculation circle of electricity bill	Provinces or regions
I	Yes	Yearly	Anhui, Jiangsu, Heilongjiang, Jilin, Shandong, Jiangxi, Henan, Hebei, Beijing, Liaoning, Shanghai, Zhejiang, Ningxia, Tianjin, Shaanxi, Guizhou, Shanxi, Qinghai
II	No	Yearly	Guangdong
III	Yes	Monthly	Hubei, Fujian, Chongqing, Sichuan, Gansu, West Inner Mongolia, East Inner Mongolia
IV	No	Monthly	Yunnan, Guangxi, Hainan, Hunan

year = 2160 kWh/year), and thus only the first block rate (0.565 Yuan/kWh) is used for calculating the bill. The second block rate will only be used for a month's electricity bill calculation when the cumulative electricity consumption in one year exceeds the first yearly block's upper limit in that month. By the same token, the third block rate is only used when the cumulative electricity consumption outnumbers the second yearly block's upper limit.

3. Data

National representative household-level survey data from the Chinese Residential Energy Consumption Survey 2014 (CRECS, 2014) were used. The survey was implemented as part of the Chinese General Social Survey (CGSS), the most influential social survey project in China. The sampling technique based on map addresses was adopted to ensure representativeness. The survey was conducted between July and October 2015 and recorded the 2014 household energy consumption over 28 Chinese provinces.

The CRECS 2014 data used in this paper comprise four parts: the first part contains the electricity consumption of 2014 for surveyed households, including the 2014 average monthly electricity consumption, the average monthly electricity consumption for the 2014 summer period (from June to September), and the average monthly winter electricity consumption (from November to March of the following year); the second part comprises the characteristics of the household head, consisting of gender, age, and educational level; the third part includes household characteristics, consisting of annual household income, family size, and having teenagers or not; and the fourth part records the dwelling characteristics, including floor area and dwelling ownership. In addition, the geographic information for surveyed households was recorded, which enables us to distinguish the whole sample into urban and rural sub-samples, and eastern, middle, and western sub-samples. A total of 2408 observations were used for the study.

Descriptive statistics of the relevant variables are presented in Column (a) of Table 2. Our study's surveyed data are representative and consistent with the official statistics based on the comparison of key countable indicators. For example, our survey data's monthly electricity consumption (130.96 kWh) is consistent with the official records (125.38 kWh). As for the socio-demographic variable, the CRECS 2014 yields an average family size of 2.94 persons and female ratio at 0.52, which approximates the official records with the statistics of family size (2.97) and female ratio (0.49). Regarding the average per capita income, the surveyed data (21734 Yuan/person) is close to the statistics of 20, 168 Yuan/person (National Bureau of Statistics of China, 2015). Benefit from the data's share-to-public and representativeness, the CRECS data has become the most frequently used micro-level dataset for Chinese household energy consumption analysis (Zheng and Wei, 2019).

Due to the vast difference in geography, climate, economy, culture, and other conditions, the household energy consumption pattern varies greatly among regions (Wu et al., 2017, 2019). Columns (b) and (c) in Table 2 present the variance analysis for urban-rural and east–middle–west tests, respectively. The *F*-value suggests significant differences in terms of electricity consumption, household characteristics, and dwelling characteristics among those subsamples. On average, urban households consume a significantly higher electricity level per month compared to their rural counterparts. From the geographical location perspective, households in the middle area consume significantly lower electricity levels than households in the eastern area but significantly higher levels than households in the western area. Another noticeable feature is the significant difference in annual household income among subsamples: on average, urban households are wealthier than their rural counterparts; households in the eastern area are more affluent than households in the middle area, with households in western area ranking the lowest in household income. Those significant differences hint that subsamples' household electricity consumption behavior may differ significantly, and are thus highly prone to having different price and income elasticities of electricity demand.

Further, we used the CRECS data to examine whether the provincial IBEP scheme meets the NDRC's requirement. Table 3 summarizes the distribution of our sampled household electricity consumption in each of the three blocks in each province or region. It suggests two findings. First, at the aggregated level, the first block of electricity consumption comprises around 80.4% of households, with 15.4% and 4.2% of households in the second and the third blocks, respectively. This pattern is consistent with the ex-ante design objective of the IBEP policy, that is, the first block should cover the electricity consumption of about 80% of households, and the second block should cover power consumption of about 95% of households as predetermined in the NDRS's guideline. This hints that only about 20% of households would pay higher electricity bills since the policy's implementation, and the policy would not impact that payment for primary electricity demand from the remaining 80% of households.

The second finding is that there is pronounced heterogeneity in the degree of tightness of the IBEP policy. Specifically, some provinces or regions, such as Jiangsu, Hebei, Shanxi, Qinghai, Guangdong, and Fujian, defined a relatively tight first block of electricity consumption, leading to a relatively higher proportion of households in the second and third blocks. In contrast, the relatively loose design of the first block of

Table 2
Descriptive statistics of CRECS 2014.

Indicator	(a) Mean	(b) Urban-rural gap			(c) Regional gap			
		Urban	Rural	*F*-stat	East	Middle	West	*F*-stat
Average monthly electricity consumption per household in 2014 (in kWh)	130.96	160.89	110.20	124.81***	166.42	122.67	93.24	87.29*
Characteristics of household head								
Gender (male = 0, female = 1)	0.52	0.52	0.53	0.22	0.53	0.53	0.49	1.51
Age (in years)	54.73	56.10	53.80	12.09***	54.03	54.47	56.09	2.98**
Educational level[a] (No schooling = 0)								
EduD1 (1 = primary school/junior middle school/high school)	0.73	0.69	0.75	11.36***	0.69	0.76	0.72	5.75***
EduD2 (1 = junior college/undergraduate)	0.13	0.25	0.05	210.92***	0.20	0.09	0.10	27.28***
EduD3 (1 = postgraduate or above)	0.01	0.02	0.00	20.82***	0.02	0.00	0.00	11.97***
Household characteristics								
Household annual income (in Yuan)	63899.48	82445.74	50591.68	23.01***	94322.19	46019.96	38980.29	24.06***
Family size (in persons)	2.94	2.74	3.08	35.56***	2.83	3.01	2.96	3.98**
Teenagers (No = 0, Have = 1)	0.29	0.24	0.33	21.39***	0.32	0.28	0.27	1.74
Dwelling characteristics								
Floor area (in square meter)	121.29	98.29	137.79	137.41***	105.45	127.88	133.45	24.95***
Owned (rented = 0, owned = 1)	0.90	0.87	0.91	8.99***	0.85	0.93	0.91	16.77***

Note: ***, **, and * indicate significance at 1%, 5%, and 10%, respectively.
[a] The variable of educational level has four categories and thus three dummy variables (EduD1, EduD2, and EduD3) are introduced, similarly hereinafter.

Table 3
Distribution of household electricity consumption in each block by province.

Province or region	Sample size	Proportion in 1st block (%)	Proportion in 2nd block (%)	Proportion in 3rd block (%)
Overall	2408	80.4	15.4	4.2
Anhui	117	84.6	10.3	5.1
Jiangsu	116	72.4	18.1	9.5
Heilongjiang	132	81.1	16.7	2.2
Jilin	115	86.1	10.4	3.5
Shandong	163	93.9	4.3	1.8
Jiangxi	127	73.2	26.0	0.8
Henan	168	72.0	22.0	6.0
Hebei	62	74.2	11.3	14.5
Beijing	96	76.0	17.7	6.3
Liaoning	84	77.4	15.5	7.1
Shanghai	56	94.6	3.6	1.8
Zhejiang	75	77.3	17.3	5.4
Ningxia	23	91.3	8.7	0.0
Tianjin	68	76.5	17.6	5.9
Shaanxi	98	87.8	12.2	0.0
Shanxi	52	65.4	23.1	11.5
Qinghai	23	60.9	26.1	13.0
Guangdong	81	65.4	28.4	6.2
Guizhou	50	74.0	22.0	4.0
Hubei	134	81.3	17.9	0.8
Fujian	54	57.4	37.0	5.6
Chongqing	72	87.5	11.1	1.4
Sichuan	143	96.5	2.8	0.7
Gansu	58	94.8	3.4	1.8
Yunnan	49	81.6	8.2	10.2
Guangxi	53	77.4	18.9	3.7
Hunan	115	76.5	21.7	1.8
West Inner Mongolia	24	95.8	4.2	0.0

Note: There are no samples in Hainan and East Inner Mongolia. Thus, there are no corresponding data.

electricity consumption can be found in Shandong, Shanghai, Ningxia, Shaanxi, Sichuan, Gansu, and West Inner Mongolia, yielding about 95% of households in the first block. An over-tight design of the three electricity consumption blocks would cause an unexpected increase in the electricity bill of middle- or low-income groups. On the contrary, an over-loose design of electricity consumption blocks would weaken the policy's original intention to guide residents to reduce excessive electricity consumption.

Compared with studies using aggregated data, our unique household-level data offer more information on the distribution of household electricity consumption within the three blocks. This feature enables us to apply the following new estimation strategy with instrumental variables.

4. Estimation strategy with instrumental variables

4.1. Establishing instrumental variables

In an increasing-block electricity pricing scheme, the block marginal rate charged to a consumer changes in a step-wise fashion with the quantity demanded (Reiss and White, 2005). Meanwhile, the residential electricity consumption behavior is expected to change to an energy-saving mode with an increase in the marginal block rate (Yu and Wang, 2020). It is difficult to determine how to incorporate the complex price schedule into the demand specification in an empirical study, due to the simultaneous determination of marginal price and electricity consumption. The ordinary least squares (OLS) method will yield biased and inconsistent estimates if an inappropriate marginal price variable is chosen (Dharmaratna and Harris, 2012). The average electricity price is commonly used in the literature as the alternative price variable in the specification. However, the average electricity price problems - such as consumer unresponsiveness, endogeneity, and measurement error - are very likely to cause a biased estimation (Alberini and Filippini, 2011).

To address the endogeneity issue of electricity marginal price under increasing-block pricing policy, we follow previous work to construct instrumental variables for electricity marginal price and annual household income (Billings, 1982; Hung and Huang, 2015), which will be used in the following econometric models. This methodology creates a set of instrumental variables for each legal rate structure that corresponds to the marginal price and income difference parameters. It assumes that consumers will roughly estimate the whole rate structure from a linear regression of the theoretical electricity bills to obtain the price information and consume electricity accordingly. Because the instrumental variables are predetermined and vary over the rate structures, no feedback regarding the effect of quantity on price can be obtained. This method appears to be appropriate for mainland China since only a small fraction of households fully understand the complicated and relatively new IBEP policy (Zheng and Wei, 2019). The estimation strategy has been proved to produce good statistical estimation and has been applied in case studies involving increasing or decreasing electricity or water pricing policies, such as Agthe and Billings (1996), Martínez-Espiñeira and Nauges (2004), and Hung and Huang (2015).

The general steps to establish instrumental variables are as follows.

First, we obtain the minimum and maximum value of our sampled households' electricity consumption (in kWh) under a specific IBEP scheme in a province or region. Based on a 1 kWh increment from the minimum value to the maximum value, a series of electricity consumption samples can be derived as follows.

$$\Omega = \{E_{\min}, E_{\min}+1, E_{\min}+2, ..., E_{\max}\} \quad (1)$$

Take Anhui province as an example. It falls into the Type I group of IBEP schemes in Table 1. Concerning the yearly household electricity consumption of 2014 for households in Anhui, the sampled minimum value is 120 kWh, and the sampled maximum value is 4800 kWh. Accordingly, based on 1 kWh increment from the minimum value to the maximum value (120 kWh, 121 kWh, 122 kWh, …, 4800 kWh), a total of 4681 electricity consumption samples are produced.

Second, we calculate its corresponding theoretical electricity bill (*TEB*) for each of these sampled electricity consumptions ($E \in \Omega$) obtained in the first step as follows.

$$TEB = \begin{cases} E \times p_1, E \leq q_1 \\ q_1 \times p_1 + (E - q_1) \times p_2, q_1 < E \leq q_2 \\ q_1 \times p_1 + (q_2 - q_1) \times p_2 + (E - q_2) \times p_3, E > q_2 \end{cases} \quad (2)$$

where p_1, p_2, p_3 are the first electricity block rate, the second block rate, and the third block rate in the IBEP policy in a specific province, respectively; q_1 and q_2 are the upper limits of the first block and the second block of electricity consumption.

Third, these *TEB* values are regressed against their corresponding *E* values to have the following fitted model.

$$TEB_k = a + bE_k + \eta_k \quad (3)$$

where η_k is the stochastic disturbance to capture effects other than income.

Fourth, the estimated slope of $\widehat{b}$ is the instrumental variable P_{IV} for the marginal electricity price. The estimated intercept $\widehat{a}$ represents the income difference variable D_{IV} ($D_{IV} = \widehat{a} = \widehat{TEB} - \widehat{b}E$)· D_{IV} measures the difference between the actual electricity bill paid by residents and the hypothetical electricity bill under a single marginal electricity price. It can be interpreted as the government subsidy to households under the IBEP policy (Taylor, 1975; Nordin, 1976). It corresponds to the income effect brought about by the change of the consumer budget line. Accordingly, the instrumental variable for household income (I_{IV}) is obtained by surveyed household annual income (I) minus D_{IV}, as follows.

$$I_{IV} = I - D_{IV} \quad (4)$$

Table 4 lists the detailed procedure to establish instrumental

Table 4
Detailed description of operational steps to derive instrumental variables.

Type	Description of operations
I	a) Each block's monthly electricity consumption in each province multiplies by 12 to obtain each block's yearly electricity consumption. b) The monthly electricity consumption of each surveyed household multiplies by 12 to obtain the yearly electricity consumption of 2014. c) We perform the general four steps described above to establish the instrumental variables for yearly marginal electricity price and yearly household annual income for each province.
II	a) Each block's monthly electricity consumption across one year in Guangdong province is aggregated to obtain the yearly electricity consumption of each block. b) The monthly electricity consumption of each surveyed household multiplies by 12 to obtain the yearly electricity consumption of 2014. c) We perform the general four steps described above to establish the instrumental variables for yearly marginal electricity price and yearly household annual income.
III	a) Using the monthly electricity consumption of each block and the monthly electricity consumption of each surveyed household in each province, we perform the general four steps described above to establish the instrumental variables for yearly marginal electricity price and monthly income difference variable. b) The monthly income difference variable DIV multiplies by 12 to obtain the yearly income difference variable in each province. c) The instrumental variable for yearly household annual income IIV is derived from the annual household income minus the yearly income difference variable in each province.
IV	a) For each increasing-block rate scheme under specific periods in each province, say the wet season (from May to November) in Yunnan province, we calculate the average monthly electricity consumption for each surveyed household, the sampled monthly electricity consumption E, and the corresponding monthly TEB. b) The sampled monthly electricity consumption E and the corresponding monthly TEB from all periods are pooled together in each province. c) For each province, use the pooled monthly data to perform the general third step to obtain the instrumental variables for the yearly marginal electricity price and the monthly income difference variable. d) The monthly income difference variable DIV multiplies by 12 to obtain the yearly income difference variable in each province. e) The instrumental variable for yearly household annual income IIV is derived from the annual household income minus the yearly income difference variable in each province.

variables.

Table 5 summarizes the instrumental variables for the marginal electricity price P_{IV} and the yearly income difference variable D_{IV}. Both instrumental variables will be used in the following econometrical analysis. The mean of P_{IV} is 0.644 Yuan per kWh, with the minimum value of 0.434 Yuan per kWh in West Inner Mongolia and the maximum value of 0.793 Yuan per kWh in Anhui. D_{IV} ranges from -557.20 Yuan in Beijing to -3.11 Yuan in West Inner Mongolia, with a mean of -247.02 Yuan.

Table 5
Instrumental variables in each province.

Province	P_{IV}(Yuan/kWh)	D_{IV}(Yuan)	Province	P_{IV}(Yuan/kWh)	D_{IV}(Yuan)
Anhui	0.793	-536.81	*Shaanxi*	0.523	-28.50
Jiangsu	0.717	-468.85	*Shanxi*	0.582	-142.43
Heilongjiang	0.542	-34.45	*Qinghai*	0.572	-307.88
Jilin	0.684	-242.42	*Guangdong*	0.789	-542.99
Shandong	0.648	-189.04	*Guizhou*	0.642	-394.11
Jiangxi	0.692	-147.80	*Hubei*	0.601	-36.70
Henan	0.661	-134.90	*Fujian*	0.611	-240.64
Hebei	0.667	-241.77	*Chongqing*	0.624	-193.68
Beijing	0.698	-557.20	*Sichuan*	0.684	-254.22
Liaoning	0.729	-455.69	*Gansu*	0.564	-61.83
Shanghai	0.742	-275.84	*Yunnan*	0.580	-232.69
Zhejiang	0.749	-555.50	*Guangxi*	0.679	-231.15
Ningxia	0.575	-95.32	*Hunan*	0.714	-240.32
Tianjin	0.536	-70.68	*West Inner Mongolia*	0.434	-3.11

Note: There are no samples in Hainan and East Inner Mongolia, and thus there are no corresponding instrumental variables.

4.2. Econometric model specification

The residential demand for electricity can be defined as follows:

$$E = f(X) \tag{5}$$

where X is the determinants of household electricity demand. In light of the literature discussion and the available variables in our data, the present study includes the following factors: electricity price, household income, characteristics of household head, household characteristics, and dwelling characteristics (Hondroyiannis, 2004; Brounen et al., 2012; Jones et al., 2015; Jones and Lomas, 2015). Then, the model to be estimated has the following specific form:

$$\begin{aligned}\ln E_i = \alpha_0 + \alpha_1 \ln P_{IV,i} + \alpha_2 \ln I_{IV,i} + \alpha_3 Gender_i + \alpha_4 Age_i \\ + \alpha_5 EduD1_i + \alpha_6 EduD2_i + \alpha_7 EduD3_i + \alpha_8 Familysize_i \\ + \alpha_9 Teenagers_i + \alpha_{10} Floorarea_i + \alpha_{11} Owned_i + \varepsilon_i\end{aligned} \tag{6}$$

where E_i is the i-th household's annual electricity consumption in 2014; $P_{IV,i}$ is the instrumental variable for the electricity marginal price faced by household i living in the corresponding province, as displayed in Table 5; $I_{IV,i}$ is the instrumental variable for annual household income that is obtained as per Equation (2), namely by using surveyed annual income of household i minus the yearly difference variable D_{IV} in the corresponding province in Table 5. The descriptive statistics for the variables of the household head's characteristics (*Gender*, *Age*, *EduD*1, *EduD*2, *EduD*3), household characteristics (*Familysize*, *Teenagers*), and dwelling characteristics (*Floorarea, Owned*) are listed in Table 2 ε_i is the stochastic disturbance term, and α_0, $\ldots\alpha_{11}$ are the parameters to be estimated. Among them, α_1 and α_2 are the short-run price elasticity and income elasticity of residential electricity demand, respectively.

5. Results and discussion

5.1. The whole sample

Model (6) was first estimated by using OLS. The whole sample result is presented in Column (a) in Table 6. We also added the dummy variable of *Urban* (1 = urban, 0 = rural) to test whether there is a significant difference in electricity consumption between urban and rural residents. The result of the urban-rural test is listed in Column (b) of Table 6. Moreover, the east–middle–west regional heterogeneity test, conducted by including two dummy variables of *Middle* (1 = Middle,

Table 6
Estimated results for the whole sample.

Variables	(a)	(b)	(c)
lnP_{IV}	-0.953*** (0.122)	-0.903*** (0.120)	-0.455*** (0.131)
lnI_{IV}	0.207*** (0.015)	0.164*** (0.015)	0.178*** (0.015)
Gender	0.052* (0.030)	0.035 (0.029)	0.036 (0.029)
Age	0.002* (0.001)	0.000 (0.001)	0.002 (0.001)
EduD1	0.293*** (0.047)	0.206*** (0.048)	0.265*** (0.047)
EduD2	0.407*** (0.066)	0.216*** (0.069)	0.359*** (0.065)
EduD3	0.268 (0.166)	0.050 (0.165)	0.162 (0.164)
Familysize	0.087*** (0.012)	0.092*** (0.011)	0.091*** (0.011)
Teenagers	0.068* (0.036)	0.082** (0.036)	0.055 (0.036)
Floorarea	0.000*** (0.000)	0.001*** (0.000)	0.001*** (0.000)
Owned	0.055 (0.050)	0.060 (0.049)	0.065 (0.049)
Constant	4.520*** (0.196)	4.985*** (0.200)	4.376*** (0.197)
Urban		0.310*** (0.034)	
Middle			0.244*** (0.038)
East			0.413*** (0.043)
Observations	2408	2408	2408
Adjusted R^2	0.187	0.213	0.216

Notes: Standard error in parentheses. ***, **, and * indicate significance at 1%, 5%, and 10%, respectively.

0 = otherwise) and *East* (1 = East, 0 = otherwise), is reported in Column (c) of Table 6.

As shown in Column (a) of Table 6, the overall national price elasticity of residential electricity demand (-0.953) is less than 1 (in absolute term), meaning that a one percent increase in electricity price will lead to a less than one percent decrease in electricity consumption. It means that the demand for electricity is inelastic. Income elasticity is estimated to be 0.207. It means that a one percent increase in annual household income will lead to a less than one percent increase in electricity consumption, indicating that electricity is a necessary commodity for households. As with other factors affecting household electricity demand, females tend to consume significantly more electricity than males, and the older the head of household, the more electricity the household consumes. Compared with the head of the household having no schooling, individuals with an education level of up to junior college or undergraduate have a significantly higher electricity demand. In addition, households with teenagers consume significantly more electricity than their counterparts with no teenagers. Further, the larger the family size and floor area, the higher the household electricity consumption level.

When adding dummy variables to distinguish different categories of households, the estimated results of Columns (b) and (c) have higher Adjusted R^2 values compared with Column (a) in Table 6, hinting that the location feature of households matters for estimating household electricity demand. On average, urban households consume a significantly higher level of electricity than their rural counterparts. Compared with households living in the western area, households in the eastern or middle areas have a significantly higher electricity demand. Further evidence of the differentiated household electricity consumption behavior among different subsamples is the change in price and income elasticity. As for the perspective of an urban or rural area, price elasticity declines from 0.953 to 0.903 (in absolute terms), and income elasticity decreases from 0.207 to 0.164. As with the perspective of the eastern, middle, and western areas, price elasticity declines by almost half, from 0.953 to 0.455, and income elasticity declines from 0.207 to 0.178.

Given the evidence above, which points to the potential differentiated electricity consumption behavior among different subsamples, it is highly probable that different categories of households have significantly different price elasticity and income elasticity of electricity demand. Thus, it is necessary to estimate the two indicators for each subsample.

5.2. The heterogeneity in subsamples

In this section, the whole sample is divided into urban and rural households to fit Equation (6). The estimated results are summarized in Column (a) in Table 7. As for price elasticity, the two subsamples have almost the same estimation (both around -0.875). However, for income elasticity, it declines significantly from 0.198 in urban areas to 0.137 in rural areas, meaning that a one percentage point increase in annual household income will bring about more electricity consumption for urban households than for their rural counterparts. As with other determinants of electricity demand (apart from family size and floor area that have similar influence mechanisms), educational level of the head of household, having teenagers or not, and dwelling ownership show different influence patterns in urban and rural areas. Specifically, in urban areas, household heads with junior college or undergraduate education consume a significantly higher level of electricity than those with no schooling, whereas no such impact exists in rural areas. Regarding family composition, rural households with teenagers consume significantly more electricity than those with no teenagers. When it comes to dwelling ownership, only in urban areas do house owners consume a higher electricity level than renters.

Column (b) in Table 7 presents the estimated results for the subsamples from the eastern, middle, and western areas, respectively. The price elasticity is estimated to be -0.639 for eastern households. It declines significantly for households in the middle and western areas to around -0.410. As with income elasticity, eastern and western households' values are almost the same (around 0.185) but decline slightly for households living in the middle area (0.165). With reference to other influencing factors, family size and floor area have similar influence mechanisms for all subsamples. Except for the household head's age, the factors only have a significant impact in the eastern area. Regarding the household head's educational level, the group with postgraduate or higher education significantly increases electricity consumption in the eastern area while significantly decreasing the power demand in the middle area. Only in the western area do households with teenagers consume a higher level of electricity than households with no teenagers. As with dwelling ownership, compared with renters, households that own the dwelling tend to consume more electricity.

Table 7
Estimated results for Urban-Rural and East-Middle-West area.

Variables	(a) Urban-rural gap		(b) Regional difference		
	Urban	Rural	East	Middle	West
$\ln P_{IV}$	-0.878***	-0.871***	-0.639***	-0.413**	-0.410*
	(0.181)	(0.162)	(0.249)	(0.201)	(0.247)
$\ln I_{IV}$	0.198***	0.137***	0.181***	0.165***	0.191***
	(0.028)	(0.019)	(0.027)	(0.024)	(0.030)
Gender	0.016	0.042	0.069	0.031	-0.022
	(0.043)	(0.040)	(0.050)	(0.046)	(0.059)
Age	0.001	-0.003	0.005**	-0.001	0.001
	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)
EduD1	0.290***	0.166***	0.229**	0.262***	0.247***
	(0.109)	(0.055)	(0.096)	(0.071)	(0.083)
EduD2	0.311**	0.147	0.311***	0.372***	0.364***
	(0.123)	(0.111)	(0.116)	(0.109)	(0.133)
EduD3	0.166	0.127	0.348*	-0.750*	—[a]
	(0.196)	(0.518)	(0.200)	(0.411)	
Familysize	0.092***	0.091***	0.106***	0.088***	0.073***
	(0.019)	(0.014)	(0.020)	(0.018)	(0.022)
Teenagers	0.006	0.111**	0.016	0.041	0.140*
	(0.053)	(0.049)	(0.059)	(0.057)	(0.074)
Floorarea	0.001***	0.001***	0.001**	0.001**	0.001***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Owned	0.142**	-0.032	0.196***	-0.015	-0.140
	(0.065)	(0.073)	(0.072)	(0.089)	(0.106)
Constant	4.622***	5.492***	4.542***	4.984***	4.495***
	(0.342)	(0.270)	(0.343)	(0.311)	(0.379)
Observations	1006	1402	855	960	593
Adjusted R^2	0.177	0.164	0.151	0.160	0.169

Notes: Standard error in parentheses. ***, **, and * indicate significance at 1%, 5%, and 10%, respectively.
[a] Indicates that there is no variable in the west subsamples.

5.3. Comparison with related studies

We compared our estimates with previous studies (the selected literature is listed in Supplementary Table 1). Fig. 2 illustrates the price and income elasticity of high-income economies and middle-income economies (Bernard et al., 2011; Dilaver and Hunt, 2011; Donatos and Mergos, 1991; Filippini and Pachauri, 2004; Halicioglu, 2007; Holtedahl and Joutz, 2004; Hunt et al., 1998; Narayan and Smyth, 2005; Yoo et al., 2007; Ziramba, 2008). First, it shows that the high-income group has a greater mean value and variation than their middle-income counterparts in terms of price elasticity. For example, the high-income group covering 12 economies from 20 studies has a mean of -0.48 for price elasticity, of which Japan holds the highest score (-1.204) and Spain the lowest value (-0.07) among the 20 estimates. As for the middle-income group that covers five countries (Turkey, Honduras, South Africa, India, China) from ten studies, the mean short-run price elasticity is -0.38, of which China has the largest value (-0.65) and South Africa the lowest (-0.02). Our overall estimate of price elasticity (-0.953) is consistent with Kamerschen and Porter (2004)'s estimate for the US, but greater than the China-related estimates. One interpretation is that our 2014 data had

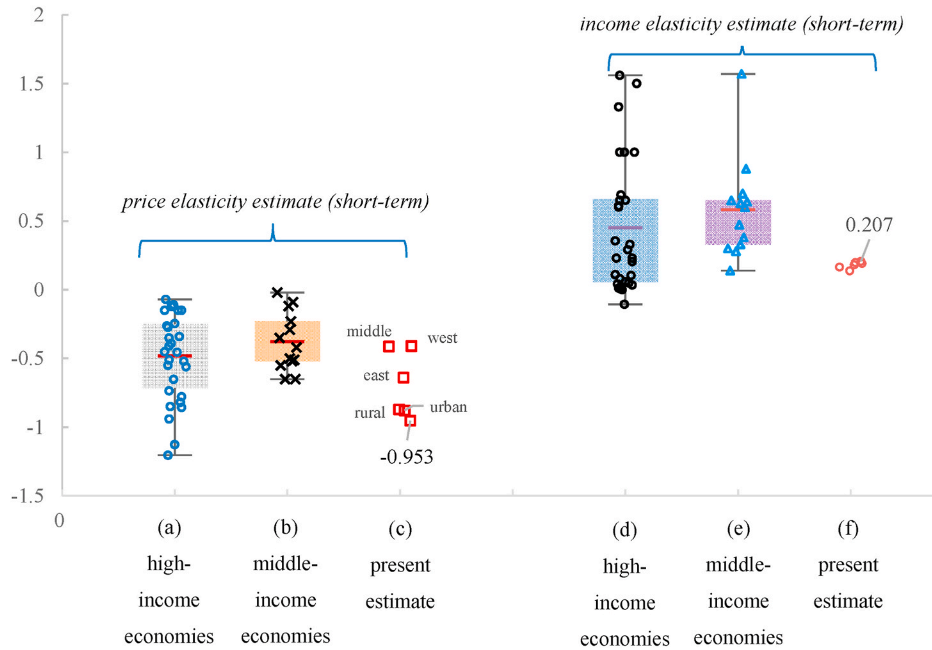

Fig. 2. Comparison of price and income elasticities of household electricity demand.

captured the price effect result from the IBEP reform launched in 2012. While previously having no interest in price, households in the post-IBEP era began to perceive and make more positive and sensitive responses to the price constraint (Yu and Wang, 2020).

Moreover, our subsamples estimates suggest that urban and rural residents have similar price elasticity (-0.878 and -0.871, respectively). However, the regional disparity is far greater. For example, middle and western households' price elasticity is -0.413 and -0.41, respectively, and fall in the confidence interval and close to the mean of estimates of the middle-income group. Contrarily, the residents in the eastern area are more elastic to price changes. Eastern households' price elasticity (-0.639) is much higher than those of the middle and western counterparts and close to those of Switzerland (Filippini, 2011) and India (Bose and Shukla, 1999).

Regarding the short-run income elasticity, the high-income group shows greater variation with a mean of 0.45 and a range of -0.106 (Switzerland) to 1.56 (Greece). Despite the middle-income group having fewer observations, it yields a similar pattern with great variation and a mean estimate of 0.58. Within the middle-income group, Honduras has the greatest income elasticity (1.57), while one of China's estimates holds the lowest score (0.14). As for our result, the overall estimate (0.207) is much closer to Blázquez et al. (2013)'s estimate for Spain (0.23) and Cao et al. (2019)'s estimate for China (0.28). Another finding is that our estimates based on sub-samples are densely clustered, suggesting that the urban-rural gap and regional disparity in terms of income elasticity are relatively small, that is, urban (0.198) is slightly higher than rural (0.137), while the income elasticities for east, middle, and west are 0.181, 0.165, and 0.191, respectively.

6. Conclusion and policy implications

This study estimates the short-run price and income elasticities of residential electricity demand in China using the unique nationally representative household survey data from CRECS 2014. Instrumental variables for electricity price and household income are used to address the problem of simultaneous determination of marginal price and electricity consumption under IBEP policy. Results show that the residential demand for electricity is price inelastic and that electricity is a necessary commodity for households in the short run. As with price elasticity, the national estimation is -0.953 but declines to about -0.87 from urban to rural areas. However, from the perspective of eastern, middle, and western areas, the price elasticity for households in the middle and western areas (around -0.41) is lower than those in the eastern area (-0.639). As for income elasticity, rural households or households in the middle area have a relatively lower value of around 0.15, while the whole sample, urban households, or households in the eastern and western areas have a slightly higher value at around 0.20.

Our estimation using the established instrument variables with the latest household survey data in terms of the whole nation and the heterogeneity in subareas facilitates a better understanding of households' electricity consumption behavior in China. Furthermore, it provides valuable insights for the present IBEP policy, as follows.

First, local governments need to adjust the setting of electricity consumption in each block and each block rate appropriately, based on the timely ex-post evaluation of policy implementation. Meanwhile, the IBEP policy needs to be re-elaborated against the differential stage of the social transition goal. Although each province or region enact their own ex-ante specific policy design according to the local physical and geographical environment and economic development level, some provinces or regions set relatively tight designs of three electricity consumption blocks. In contrast, some areas set relatively loose designs. This causes ex-post inconsistency in household electricity consumption distribution, with the basic principle initially determined by the NDRC. Under the premise of ensuring that most households' electricity expenditure will not increase significantly, a larger rise in the third block rate can be considered to enhance the policy's regulatory effect on high electricity-demand households.

At the higher level, one purpose of the nationwide implementation of the IBEP policy serves China's urgent social goal of energy conservation and emissions reduction around the year 2012. However, in recent years, it has gradually become the concern of social transformation to encourage the residential sector's electrification to reduce pollutants discharge. Consequently, how to adjust IBEP policy to better conform to the substantial increase in electricity consumption level in the residential sector, and thus better serve the differential stage of social development, constitutes a new yet significant focus.

Second, considering the relatively moderate policy effect of the current IBEP and the inevitable surge in electricity demand in China's residential sector, other effective policies are needed to cooperate with IBEP policy to conduct effective management of residential electricity demand. From one perspective, according to the basic principle of IBEP by the NDRC and the coarse ex-post evaluation of the distribution of sampled household electricity consumption, around 95% of samples fall in either the first or the second block. Further, based on the estimated price elasticities in terms of either the whole sample or the subsamples, the demand for electricity is inelastic. These two facts mean that the current IBEP policy is moderate, and the effect of managing residential electricity demand through electricity pricing policy is limited.

On the other hand, China's residential electricity demand is bound to surge in the foreseeable future. With the continuous improvement of household income level, the total electricity demand is about to increase, based on the short-term income elasticity for the whole sample. Further, less developed areas in China would experience continuous household income growth, thus leading to a surge in electricity demand. Specifically, compared with their counterparts, rural, middle, and western areas for now remain at the statistically relatively lower level of electricity consumption and household income. Judging from the positive and significant short-term income elasticity, and from the fact that more affluent households have significantly higher income elasticity, residential demand for electricity in the less developed area in China is bound to increase with the continuous improvement of household income of rural, middle, and western areas toward to their relatively affluent counterparts. Moreover, the growth rate is likely to accelerate due to the switch of income elasticity to a higher level.

Consequently, based on the moderate effect of the current IBEP policy and the inevitable surge in residential electricity demand, other practical policies are needed to cooperate with IBEP policy to manage residential electricity demand. These include policies to improve home appliances' energy efficiency (The China Energy Label Program, for instance) and more aggressive publicity activities (Information feedback using the smart meter, for instance) to cultivate residents' electricity-saving behavior.

Third, more studies on ex-post evaluation of IBEP policy are needed to optimize the policy design and balance different policy objectives. Due to data unavailability, few studies have been conducted on the IBEP policy effect, although it has been in effect for eight years. For instance, Yu and Wang (2020) quantified the electricity-saving effect of the nationwide implementation of the IBEP policy using a county-level panel dataset from four provinces and a province-level panel dataset from 22 provinces from 2009 to 2015. They concluded that the policy reduced the monthly household electricity consumption by 6.5%. However, according to the 2014 national household survey conducted by Zheng and Wei (2019), only 57% of respondents knew IBEP policy, and only 48% of respondents understood IBEP policy. Besides, only 27% of respondents had received the notice information about the policy from power companies. Household perception accuracy of the IBEP policy, whether the policy has significantly changed residents' electricity consumption behavior, and the attainment level of other policy objectives need more empirical evidence based on multidisciplinary tools and methods.

CRediT authorship contribution statement

Jun-Jun Jia: Conceptualization, Data curation, Formal analysis, Funding acquisition, Methodology, Resources, Writing – original draft, Writing – review & editing. **Jin Guo:** Formal analysis, Methodology, Writing – original draft, Writing – review & editing. **Chu Wei:** Conceptualization, Formal analysis, Funding acquisition, Methodology, Project administration, Resources, Writing – original draft, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

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