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ANALYSES ON RESIDENTIAL ENERGY DEMAND AND ENVIRONMENTAL EMISSION CHARACTERISTICS IN URBAN CHINA

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ABSTRACT

The characteristics of residential energy consumption and environmental emission in urban China was focused in this paper. For that, consumer expenditure items of urban residents (1997~2015) was reclassified into five categories i.e., Food, Residential energy use, Housing and household appliances, Transport and communication, Other goods and services. The expenditure consumer price indexes of new categories were calculated. We reclassified industrial sectors of Chinese environmentally extended input-output (CEEIO) accordingly. An Almost Ideal Demand System (AIDS) was employed to calculate price and expenditure elasticity of residential energy demand. The Economic Input-Output Environmental Life Cycle Assessment (EEIO-LCA) method was introduced to estimate cumulative energy consumption and environmental emissions per monetary unit considering the whole life cycle perspective. We found that during the period of 1997~2015, for each 1% increase in household income, there would be a 1.13% increase in energy use. The uncompensated demand price elasticity was -0.2096, while the compensated was -0.2565. The cumulative energy consumption and environmental emission intensities of each sectors show continued steady decline trends. Specifically, For each 10000 yuan of expenditures, energy consumption, CO_2, nitrogen oxides, SO_2, smoke and dust emission decreased from 2.9848tce, 26.2843t, 0.1005t, 0.0962t and 0.0677t in 1997 to 1.6161tce, 8.192t, 0.0182t, 0.0172t and 0.0087t in 2015 respectively, which declined at an average annual rate of 18.49%、32.2%、43.66%、43.42%、49.54% respectively. It means that the energy and environmental efficiency in Chinese urban residential sector has been improved dramatically for nearly two decades.

Keywords: Demand analysis; Almost Ideal Demand System; Economic Input-Output Environmental Life Cycle Assessment; Cumulative environmental emission intensity

1. INTRODUCTION

The household sector has become the second largest consumer of final energy, ranking only next to the industrial sector in China. People's consumption activities also indirectly affect the energy consumption of multiple production sectors (Ding et al., 2017). Studies on residential energy consumption pattern and expenditure elasticities of residential energy demand (e.g., Sun and Ouyang, 2016) have been carried out, meanwhile, research on total requirements and requirements per consumption category also drew a great attention in recent years(Kok et al., 2006; Liu et al., 2011; Zhu et al., 2012; Zhang et al. 2013; Das and Paul, 2014; Chen et al., 2019), while this paper attempted to combine both of them together to explore residential energy demand and environmental emission characteristics in urban China. Most important, the results of this study would be used as basic material for residential rebound effect research (Wang et al., 2019).

The Almost Ideal Demand System (AIDS) method stems from Engel Curves which relates the budget shares and the logarithm of total expenditure, and this method integrates the indirect utility function that enable to include price effects, and uses utility maximization to obtain theoretical restrictions. It is widely used in demand analysis research as it unifies almost all theoretically and empirically desirable properties, especially for the linear approximation of the AIDS (LA-AIDS; Deaton and Muellbauer, 1980a, b; Henningsen,

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2011). Environmentally–economic input–output life cycle assessment (EIO-LCA) was popular to explore the cumulative energy consumption and environmental emission corresponding to different consumption patterns for an average urban household (Hendrickson et al. 2006; Lenzen et al. 2004, 2006; Thomas and Azevedo 2013). By combining economic and energy (or environmental) data, this analytical method is usually applied to assess the resource requirement and environmental impacts resulting from the production and consumption of goods and service for the whole economy (Cellura et al., 2011).

This study is arranged as follows. The following section is about the data matching. Section 3 provides the model specification: AIDS and EIO-LCA. Section 4 shows the empirical results and discussion.

2. PAPER STRUCTURE

2.1 Data

2.1.1 Data sources

Data used in this paper mainly includes three aspects: ① Consumption expenditure of urban households by region and its composition (1997~2015): China Statistical Yearbooks (1998~2016); DRCNET Statistical Database System ; ② Urban consumer price indices by category and region, and producer price indices for industrial products by sector (1997~2015): China Price and Urban Household Income and Expenditure Survey Statistical Yearbooks (1998~2005); China Urban Life and Price Yearbooks (2006~2012); China Price Statistical Yearbooks (2013~2016); ③Energy consumption by industry: China Energy Statistical Yearbook (2009, 2014, 2016); ④ Total Output and environmental emission by sector, and energy consumption by industry and (1997, 2002, 2007, 2012): Chinese Environmentally-extended Input-Output Database (1997, 2002, 2007, 2012; http://www.ceeio.com).

2.1.2 Category adjustments

(1) The category adjustment for consumer expenditure items of urban residents

In view of the inconsistent classification framework of urban household consumption expenditure during the sample period, consumer expenditure items of urban residents (1997~2015) was reclassified as five categories firstly, i.e., Food and beverages, Energy, Housing and household appliances, Transport and communication, Other goods and services.

(2) The adjustment and calculation of expenditure consumer price indexes

After the original consumer spending items are reclassified, the expenditure consumer price indexes of new categories were calculated using Stone price index.

(3) The combination of sector production data

The combination of sector production data of CEEIO and the combination of sector production data of energy consumption by industry.

2.2 Model specification

2.2.1 Demand Model—The Linear Approximation of AIDS

In this paper, the linear approximation form of AIDS model (LA-AIDS) was employed to specify the demand system. The LA-AIDS for the *k*th group can be expressed in Equ. (1).

$$w_{(k)t} = \alpha_{(k)} + \sum_{l=1}^{n} \gamma_{(k)(l)} \ln P_{(l)t} + \beta_{(k)} \left(\ln x_t - \ln P_t \right) + u_{(k),t}; \quad (1)$$
$$u_{(k),t} \sim N(0, \Sigma),\ k = 1, \ldots, n$$

where for observation *t*, $w_{(k)t}$ is the budget share of the k th commodity group, $P_{(l)t}$ is the price index of the l th commodity group, x_t is the total nominal expenditure, and P_t is the Stone's price index defined by $\ln P_t = \sum_{k=1}^{n} w_{(k),t} \ln P_{(k)t}$, where n denotes the numbers of consumption categories. In this paper, $n = 5$, and $k, l = 1, 2, 3, 4, 5$ represents the commodity category of Food, Residential Energy Use, Housing and Household Facilities (or appliances), Transportation and Communication and Other Articles and Services respectively. Parameter $\gamma_{(k)(l)}$ is coefficient for the logarithm of *l*th group price index; $\beta_{(k)}$ is a kind of semi-elasticity of $w_{(k)t}$ with respect to real expenditure x_t / P_t, which indicates $w_{(k)t}$ would change $\beta_{(k)} / 100$ with a percentage point increase in x_t / P_t (Wooldridge, 2006). $\beta_{(k)}$ also determines whether the k th commodity group is a luxury (when $\beta_{(k)} > 0$) or necessity (when $\beta_{(k)} < 0$)(Deaton and Muellbauer, 1980a); $\alpha_{(k)}$ and $u_{(k),t}$ represent constant and error terms respectively.

Microeconomic theoretical restrictions on the econometric model apply directly to parameters to be estimated. And in the estimation of five demand function equations (see Equ. 1), the 'adding-up' condition, the ‘homogeneity’ condition and the ‘symmetry’ condition can be expressed as follows.

$$\sum_{k=1}^{n}\alpha_{(k)}=1;\ \sum_{k=1}^{n}\beta_{(k)}=0;\ \sum_{k=1}^{n}\gamma_{(k)(l)}=0,\ \forall l \tag{2}$$

$$\sum_{l=1}^{m}\gamma_{(k)(l)}=0,\ \forall k \tag{3}$$

$$\gamma_{(k)(l)}=\gamma_{(l)(k)},\ \forall k,l \tag{4}$$

Given these estimated parameters and following Goddard (1983), Chalfant (1987) and Edgerton et al.(1997), the expenditure and price elasticities can be calculated appropriately in the following way:

$$\eta_{y(k)}=1+\frac{\beta_{(k)}}{w_{(k)}} \tag{5}$$

$$\eta_{(k)(l)}=\frac{\gamma_{(k)(l)}-\beta_{(k)}w_{(l)}}{w_{(k)}}-\delta_{(k)(l)} \tag{6}$$

$$\tilde{\eta}_{(k)(l)}=\frac{\gamma_{(k)(l)}}{w_{(k)}}+w_{(l)}-\delta_{(k)(l)} \tag{7}$$

where $\eta_{y(k)}$ represents the expenditure elasticity of the *k*th commodity group; $\eta_{(k)(l)}$ and $\tilde{\eta}_{(k)(l)}$ represent uncompensated and compensated price elasticities respectively, where $\delta_{(k)(l)}$ denotes the Kronecker product that is equal to 1 when $k=l$, and 0 otherwise.

2.2.2 Energy and environmental emission analysis of household consumption

Under the assumption that all the commodity consumed by the household were produced in China, the EIO-LCA process, which captures the cumulative environmental burden factor (such as energy use and environmental emissions) requirements induced by final demand of all production sectors is organized as follows.

Let v be the character code of environmental burden factors, and specify $v=En,CO_2,SO_2,NO_X,SD$ as energy consumption, CO_2 emission, SO_2 emission, NO_X emission, and smoke and dust emission respectively. And for an environmental burden factor v, the EIO-LCA model employed in this article was described as follows.

First, the energy use or environmental emission intensity vector for the production sectors $\mathbf{F}_v^{pro}$ is determined via

$$\mathbf{F}_v^{pro}=\mathbf{D}_v\hat{\mathbf{q}}^{-1} \tag{8}$$

where $\mathbf{F}_v^{pro}$ is a $1\times m$ vector with elements $\mathbf{F}_{v\_j}^{pro}$ representing the direct factor requirement for the production of a monetary unit value of the total output of the j th sector ($j=1,\cdots,m$), where m denotes the numbers of industrial (or product) categories[1]. In this paper, $m=6$, and $j=1,2,3,4,5,6$ represents the category of Food, Residential Energy Use, Housing and Household Facilities, Transportation and Communication, Other Articles and Services , and Non-Consumer Product respectively. $\mathbf{D}_v$ is a $1\times m$ vector of environmental burden factors used (or discharged) directly in each sector but not in other upstream supply chain sectors. $\hat{\mathbf{q}}$ is a $m\times m$ diagonal matrix of total output for the industrial sectors in the input-output tables.

Then, according to the basic input-output model, supply chain energy consumption or environmental emission intensity vector $\mathbf{F}_v^{sup}$ can be obtained:

$$\mathbf{F}_v^{sup}=\mathbf{F}_v^{pro}(\mathbf{I}-\mathbf{A})^{-1} \tag{9}$$

where $\mathbf{F}_v^{sup}$ represents the embodied factor requirements throughout the supply chain of a monetary unit of expenditure on final goods or services. $\mathbf{A}$ indicates the input–output direct requirement matrix, whose element direct requirement coefficient a_{ij} represents the required inputs from the i th sector to make a unit of output for the j th sector ($i=1,\cdots,m$ and $j=1,\cdots,m$). $\mathbf{I}$ is the $n\times n$ unity matrix. $(\mathbf{I}-\mathbf{A})^{-1}$ indicates the Leontief inverse matrix or total requirements matrix, and its element total requirement coefficient l_{ij} represents the amount by which sector i is required directly and indirectly to satisfy a unit of the final demand from sector j .

And then, for an average household, the overall urban household energy use or environmental emission E_v can be calculated from the EIO-LCA model

$$\begin{aligned}E_v&=E_v^{sup}+E_v^{hh}=\mathbf{F}_v^{cum}\mathbf{y}=(\mathbf{F}_v^{sup}+\mathbf{F}_v^{hh})\mathbf{y}\\&=(\mathbf{F}_v^{pro}(\mathbf{I}-\mathbf{A})^{-1}+\mathbf{F}_v^{hh})\mathbf{y}\end{aligned} \tag{10}$$

where E_v is the urban household environmental burden factor requirements which comprises E_v^{sup} and E_v^{hh} , indicating the requirements for supply chain to provide commodity consumption and the requirements used directly by household respectively (Lenzen and Dey 2002; Kok et al. 2006; Lenzen et al. 2004; Wang et al.

[1] For Lenzen et al. (2004), factor intensity was named as factor multiplier. Additionally, number of categories for commodities and industrial sectors in that paper, but we add a ‘non-Consumer Product’ to industrial factor, as some intermediate products playing important role in economic activities are not consumed by household in CEEIO tables.

2019). $\mathbf{y}$ denotes an $m \times 1$ vector indicating expenditure on each commodity and Non-Consumer Product for an average urban household[2]. $\mathbf{F}_v^{cum}$, $\mathbf{F}_v^{sup}$ and $\mathbf{F}_v^{hh}$ are $1 \times m$ vectors, representing the cumulative, embodied (or supply chain) and direct factor requirements for every unit of currency spent on final demand respectively. $\mathbf{F}_{v\_j}^{cum}$, $\mathbf{F}_{v\_j}^{sup}$ and $\mathbf{F}_{v\_j}^{hh}$ are the elements of them, describing the cumulative, embodied and direct energy use or environmental emission intensity of final demand on commodity j.

As factor requirement directly used by household E_v^{hh} is mainly relative to energy services like home heating, cooling, lighting and private transportation, we finally set direct energy use or environmental emission intensity $\mathbf{F}_{v\_j}^{hh}$ as

$$\mathbf{F}_{v\_j}^{hh} = \begin{cases} \pi_v^{hh} / Y & j = 2 \\ 0 & j \neq 2 \end{cases} \tag{11}$$

Where π_v^{hh} denotes the direct energy use or environmental emission of urban household sector. Y represents the total urban household consumption in input-output table.

2.3 Empirical results and discussion

2.3.1 Expenditure pattern and Consumer price indices

(1) Consumption expenditure pattern of urban household

Fig. 1 illustrates that Food and Other Articles and Services (i.e., Clothing; Household Articles and Services except Household Facilities; Health Care and Medical Services; Education, Culture and Recreation; Miscellaneous Goods and Services) are the main consumption of Chinese urban households. And the expenditure pattern over the period (i.e., 1997~2015) had revealed a downward trend in the budget share of food items and an upward trend in Residential Energy Use and Transportation and Communication items. Specifically, the share of food expenditure which stood at 46.41% in 1997 had steadily declined to the level of 34.8% in 2015, with an annual average decline of 1.59%. While at the same time, expenditure on Residential Energy Use and Transportation and Communication as percentage of total expenditure which were 5.87% and 4.19% in 1997 had gone up to the level of 9.74% and 11.4%, with an annual average growth rate of 2.85% and 5.72% respectively. And percentage share of Housing and Household Facilities and Other Articles and Services were basically steady at 6.68% and 38.4% respectively.

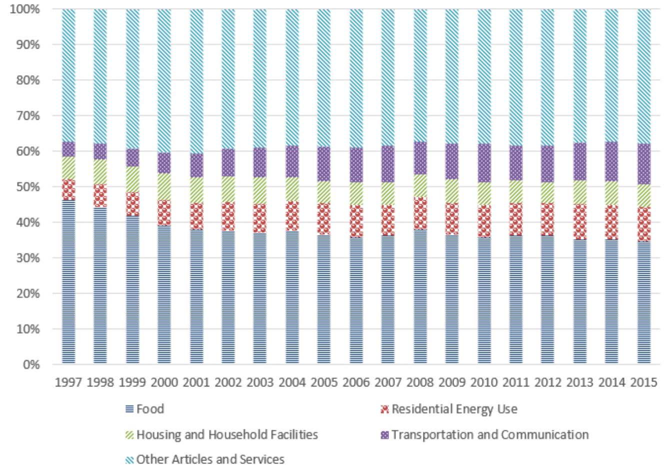

Fig.1 The composition of urban household annual living expenditure per capita (1997~2015)

(2) Consumer price indices by category of urban household

Fig. 2 shows that most of the Consumer price indices by category rose solidly with different range, except that the price index of Transportation and Communication has started to decline steadily from the early years of this century and then tended to be stable over the period 2011 to 2015.

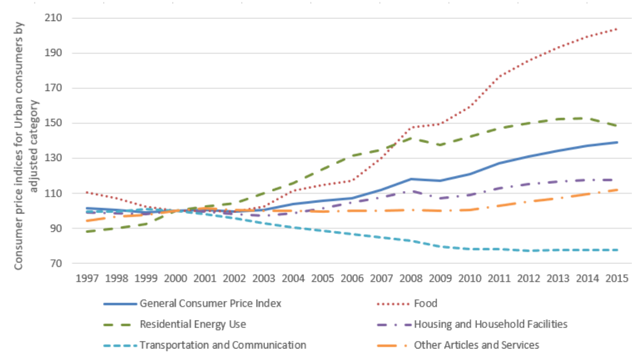

Fig. 2 Consumer price indices by category of urban household in China (1997~2015; The price index in 2000=100

Among them, food price changed in high volatility through time, which has been doubled since the current century. The energy price was characterized as an overall upward trend year by year except 2009 and 2015, and it rose at an annual average rate of 2.93% (1997~2015). The price of Housing and Household Facilities was relatively stable within the first half of sample data, while that rose steadily at an annual average rate of 1.5% in the second half. And the price of Other Articles and Services showed a slight upward tendency. And in general, urban

[2] Household expenditure on Non-Consumer Product equals zero.

household consumer price in China did not change much in the late '90s and early 2000s, but kept going up as a result of food and energy prices upward movement.

2.3.2 Income and price elasticities of demand

We adopted the program package "micEcoAids" provided by Henningsen (2011) to estimate system parameters, and selected Seemingly Unrelated Regression (SUR or SURE) as the estimation method. And the results showed that the majority of estimated values of parameter reach 0.1%, 1%, 5% or 10% significance levels. And the results of $\hat{\beta}_{(k)}$ indicate that Food is a necessity, while consumption goods like Residential Energy Use, Housing and Household Facilities, and Transportation and Communication are luxuries. Where $\hat{\beta}_{(2)}$=0.0111 means that, when real expenditure increases 1%, the budget share of Residential Energy Use rises by about 0.0001 during 1997~2015. After putting these results into Eqs.(5)~(7), we get the expenditure elasticity, uncompensated and compensated price elasticities of each commodity group and period.

We found all these five commodities are normal goods. For 1% increase of household income, there would be 0.86%, 1.13%, 1.18%, 1.45% and 0.98% increase of expenditure on Food, Residential Energy Use, Housing and Household Facilities, Transportation and Communication, and Other Articles and Services, respectively. We also found that during the period of 1997~2015, uncompensated energy demand price elasticity was -0.2096, while the compensated was -0.2565.

2.3.3 Energy and environmental emission analysis of household consumption

(1) Direct energy consumption and environmental emission intensities

From Eq.(8), we calculated the direct energy consumption and environmental emission intensities of each sectors almost unanimously decreased markedly. Specifically, for each 10000 yuan of expenditure on Residential Energy Use, direct energy consumption, CO_2, NO_X, SO_2, smoke and dust emission decreased from 1.0665tce, 14.8889t, 0.0515t, 0.0574t and 0.0282t in 1997 to 0.4109tce, 3.4288t, 0.0072t, 0.0078t and 0.0025t in 2012 respectively, which declined at an average annual rate of 27.23%、38.7%、48.1%、48.59%、55.41% respectively. It means that the energy and environmental efficiency in Chinese urban residential sector has been improved dramatically for nearly two decades.

(2) Cumulative energy consumption and environmental emission intensities

The result shows the product sector of Residential Energy Use to be of the highest cumulative energy consumption intensity (see Eq.(10)). Then the product sectors of Housing and Household Facilities, and Non-Consumer Product, followed by Transportation and Communication and then Other Articles and Services and Food. Furthermore, for cumulative CO_2, NO_x and SO_2 emission intensity, these sectors are of the same rank. While for cumulative smoke and dust emission intensity, Housing and Household Facilities sector ranks the first, followed by Residential Energy Use and Non-Consumer Product. The cumulative energy consumption and environmental emission intensities of each sectors, similar to direct intensities, show continued steady decline trends. Specifically, For each 10000 yuan of expenditures, cumulative energy consumption, CO_2, NO_X, SO_2, smoke and dust emission decreased from 2.9848tce, 26.2843t, 0.1005t, 0.0962t and 0.0677t in 1997 to 1.6161tce, 8.192t, 0.0182t, 0.0172t and 0.0087t in 2015 respectively, which declined at an average annual rate of 18.49%、32.2%、43.66%、43.42%、49.54% respectively.

2.3.4 Discussion

Our study found that residential energy demand in urban china has a potential increasing trend. During the period of 1997to 2015, residential energy demand in urban China is of price inelasticity. To further explore the demand characteristics for different energy services, deep study like two-stage AIDS is in need.

The result indicates that energy and environmental efficiency in Chinese urban residential sector has been improved dramatically, but the absolute environmental load of household consumption is still increasing. As a result, for the demand side, each individual should spare no effort to increase public environmental awareness on final consumption, by considering its cradle-to-grave energy consumption and environmental emission. Realistic program of action, such as green consumer guide, might be on the schedule. While for the production side, products with high energy and environment efficiency are broadly to be welcomed.

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