

**ARTICLE**

Impact of Demographic Transition on Household Energy Consumption: A Case from China

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ABSTRACT

Understanding how aging population and low fertility affect household energy consumption is important for optimizing household energy consumption and reaching effective policies. This paper studies the impacts of demographic transition on household energy consumption based on panel data of 30 provinces in China from 2005 to 2016. Child-age dependency rate (CDR) and old-age dependency rate (ODR) are selected to track the shifts in age structure. They are introduced into a STIRPAT model to measure their impacts on household energy consumption. Besides, 8 representative regions are additionally chosen and investigated to find some regional characteristics. The results show that current demographic transition to aging population expands household energy consumption. The aging population and low fertility cause additional challenges for energy saving and emission reduction. Household energy consumption in less developed areas is more likely to be affected by CDR and ODR. Regions with large population are also more easily influenced by demographic transitions especially CDR. This study emphasizes the effects of demographic elements on household energy consumption. It indicates that continuous optimization of household energy consumption structures should be based on population dynamics.

KEYWORDS

Demographic transition; child-age dependency rate; old-age dependency rate; household energy consumption; STIRPAT

1 Introduction

Several researches have proposed that China is expected to become the largest greenhouse gas emitter in the world [1]. China has formally set its peak time of carbon emission as around 2030 [2–4] which means carbon reduction should be done instantly. Household energy consumption plays an important role in studies on carbon emission and environmental problems. This has been approved by many researchers. For example, Druckman et al. [5] claimed that household energy consumption accounts for nearly three quarters of global carbon emissions. It is mentioned that 40% of carbon emissions growth is caused by household energy consumption from 1993 to 2007 [6]. Moreover, air pollutant emissions from Chinese households have become major source of ambient pollution [7]. Coal and crude oil, which are the main sources for carbon emission and environment pollution, make up the largest part of total energy consumption in China [8,9]. Considering this type of energy using structure and carbon reduction target, it is understandable to pay attention to energy saving. When it comes to energy saving, household energy consumption should be



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emphasized because of its large proportion of whole social energy consumption. As a result, it is necessary to clarify where the influences on household energy consumption come from. This would be helpful for the government to work out targeted policies to shape residents' household energy consumption during their daily life.

Demographic transition has great influences on household energy consumption. Residents' preferences, economic level, and life quality all have great influence on household energy consumption [10]. However, all these factors come to a critical element: Population. People with different lifestyles, income levels or other characteristics can behave differently in household energy consumption. It is said that population factors cannot be neglected when it comes to carbon emission which is led by energy consumption [11,12]. Recently, aging population and low fertility, which can affect energy utilization, have got wide attention in the literature. For example, Casey et al. [13] proved that lower fertility could reduce carbon emissions. They concluded that population policies should not be neglected during carbon emission reduction. Dalton et al. [14] found that population aging would reduce long-term emissions in the United States via inducing changes in *per capita* income. Oneill et al. [15] also claimed that population aging could reduce emissions especially in industrialized countries or regions. Many researches hold the view that population factors affect household energy consumption through economic activities. Human beings are both producers and consumers in the daily economic activities. In the long term, children would transfer to young labor so that they could influence production by affecting employment. This can affect household energy consumption by household income. Population aging works similar to that. However, the increase of the elders' proportion means a decrease of the labor share. It then decreases household income [14] and slows economic growth [15]. Specifically, different age compositions may have different energy demands [16]. According to Yu et al. [17], small and aging households can boost energy consumption through time-use and consumption patterns. The boost arises from increasing demand for heating, cooking, travel and also consumption demand from manufacturing industry including health care and education. Obviously, demographic transition should not be ignored when studying household energy consumption changes.

Low fertility and aging population are two key challenges for China during the demographic transition. In the last decade, China's age structure experienced significant transitions: The proportion of aged population has increased from 8.51% in 2003 to 11.39% in 2017; The proportion of children has decreased from 20.34% in 2003 to 16.8% in 2017. Both changes indicate that China's demographic transition is kind of rigorous. This is mainly induced by past population policies in China. Under the pressure of population structure transformation, on November 21st, 2019, Chinese government published a national plan ('China's medium- and long-term plan to actively respond to population aging') to deal with population aging both in the medium and long term. The plan points out that aging population will become an essential state of China. It puts up with bunches of social requests on various walks of life. All these evidences indicate that changes of population structure should become a prior theme. Under this background, studying population structure's influences on energy consumption is beneficial to layouts of energy development strategies and promotion of sustainable development.

However, existing researches care more about the links between aging population and energy consumption. There is a lack of attention on both low fertility and aging population and so as their influences on household energy consumption. In the short run, low fertility may cut the need for larger living space. In the long run, it could reduce the demand for energy consumption. When talking about aging population, more elders might extend the time allocated in home, this would induce more demands for heating, cooling and cooking. This further causes more consumption of electricity, gas or other types of energy. From another point of view, the elders have low desire for consumption and most of them prefer a lifestyle which is more energy saving.

As a result, this paper studies the relationships between population aging, low fertility and household energy consumption. It investigates how household energy consumption (HEC) changes with child-age dependency rate (CDR) and old-age dependency rate (ODR). To achieve this, we estimate the linkage of HEC to residential consumption level (RCL), CDR, ODR GDP and household size (HS) with a panel data. This sample considers 30 provinces, containing 360 observations that span the period from 2005 to 2016. Considering that different HEC represents specific lifestyles, generally there exists a lag effect so that previous HEC is used to help capture those real relationships. Consistent with existed literature, we find that population structure could affect household energy consumption. Under the situation that aging population and low fertility will keep in a certain term, HEC will continue to increase.

There are three main contributions of this research. First, this study uses both CDR and ODR to catch the main demographic transitions while low fertility is less focused. They could reflect the raising burden in a household better than the indicators most used in existed literature, including ratio of children, working age of population, and aging population. Both CDR and ODR are connected with people's cognition of households directly. Moreover, uncoordinated burden of families can convert to social burden. Considering this, CDR and ODR can provide significant policy implications. Second, dynamic regression model is selected to analyze the influences of household energy consumption itself. Behavior in household energy consumption is some kind of a specific lifestyle so introducing lag of that can reflect the reality more precisely. And this is also some researches did not pay attention to. Third, this study also talks about effects from different driving factors by region. The representative regions chosen by this paper are allocated around China. Climate elements, development levels, population policies, main industrial types are all taken into consideration when picking those places. Besides whole situation in China, regional differences are also investigated because of this country's vast territory. Through comprehensive and well-focused research of how demographic transition affecting household energy consumption. This paper found that developed areas are less likely to be affected by demographic transition and areas with large population could be more greatly influenced by that.

The structure of this paper is as follows. Section 2 presents a literature review concentrating on population factors of HEC, demographic transition in China and regression model; Section 3 introduces the data sources of the research and core model and method; Section 4 discusses the consequences of the empirical study; Section 5 summarizes the conclusions and puts forward policy implications from the consequences.

2 Literature Review

2.1 Driving Population Factors of Energy Consumption or Carbon Emissions

There are many literatures that presented population characteristics' effects on energy consumption or carbon emissions. Many researches paid attention to different age groups. However, whether the effect of population ages should be positive or negative is still in the debate. Actually, the results could be quite different according to specific objects. For example, Zhang et al. [18] concluded that population aging had a positive effect on China's carbon emission. Also, Menz et al. [16] also reached same effects in OECD countries. Shi [19] claimed that higher accounts of labor could lead to higher carbon emissions while Farzin et al. [20] suggested that more individuals under 15 could bring much more carbon dioxide emissions. In conclusion, different conditions on population size and composition varying in different countries and regions can lead different results.

To get an insight into population characteristics, many studies pay attention to different types of household with their HEC with household data. Mansouri et al. [21] claimed that family composition plays an important role when it comes to household energy consumption. A series of researches demonstrate that household scale is a key factor. For instance, Yu et al. [17] concluded that small and aging family makes household consumption and carbon emission increase steeply. Aging population means more old people in families. The elders are more likely to stay at home, so the heating, cooking

and cooling demand for electricity or natural gas will increase. However, the elders prefer cheap and energy-saving lifestyle and their desires for household appliances are relatively low. This also may make energy consumption drop. Under both two pathways, how aging population affect energy consumption may more influenced by the scale of the elders and their consumption level which decided by local economic development. That is to say, specific features are related to the object. In addition, Kialashaki et al. [22] reached the conclusion that household size is one of the important determinants of HEC. Some studies give the explanation of this result: larger households would consume more energy compared to smaller ones; but the former might have lower per-capita consumption [23,24].

Beside the household data, some researches use relatively macroscopic indicators like population scale or urbanization rate. However, age structure needs more attentions compared with existed studies. Wen et al. [12] constructed an extended STIRPAT model with age structure. They found that extended model could perform much better than original model. Zhu et al. [25] studied several factors' influences and revealed that household consumption level and population structure are the main contributors to carbon emissions. Besides, Yang et al. [26] found that shrinking young population and aging population would add pressures on energy consumption and environment. Impacts from young population are included by their families while aging can trigger high demands for elderly related like living services. Leahy et al. [27], and Bedir et al. [28] found that there is no significant difference in household energy consumption between families with children and those comprised of adults only. And this is consistent with that young population affect consumption demand not by themselves. Chen et al. [29] presented that family structure with one-child had a positive effect on indirect household energy demand while the family structures with two or more children presented a negative effect. The reasons are that parents will invest a lot for the first baby, but when families have a second child, the condition can be different. In families with more children, although total energy consumption requirements increase, the quantity *per capita* is expected to decrease.

2.2 Demographic Transitions

The demographic transition dominated by aging population and lower fertility is becoming more and more popular in developed countries. Because of the family planning policy, China is also facing similar transition recently and might be more serious in the future. Declines in mortality and sharp falls in fertility may bring China with rapid aging society [15]. Peng [30] claimed that China was at a demographic turning point from a young society to an old one based on country's 2010 population census. According to the census, the share of the total population aged 0 to 14 declined from 22.9% in 2000 to 16.6% in 2010 whereas proportion aged 65 and above grew from 7.0% to 8.9%. It is obvious that this kind of condition will exacerbate along with time passing.

In order to clarify the links between demographic transitions and carbon emissions or energy consumption, many researches look into how population shifts affect related driving factors. Yu [17] presented two categories of demographic transition's influences on energy consumption: time and money allocation. Demographic structure decides time allocated in work and leisure. According to Druckman [5] (2012), non-leisure activities are associated with higher carbon emissions. Meanwhile, Nässén [31] claimed that a decrease in working time by 1% could reduce energy consumption or greenhouse gas emissions by 0.7% and 0.8% respectively. It is also worth mentioning that women might consume more electricity than men because of housework [32]. Aging population require more support from working age population through family transfers and so as child-age population. Cai [33] examined demographic transition process in China and predicted a labor shortage. All these can reduce *per capita* consumption through lower income.

2.3 STIRPAT Model

In the literature, there are many empirical studies on relationships between population characteristics and energy consumption or carbon emissions. Within these researches, stochastic impacts by regression on population, affluence, and technology (STIRPAT) model is broadly utilized and extended. This model is often used to investigate influencing factors of energy consumption or carbon emissions. STIRPAT model is developed based on IPAT (I = Human Impact, P = Population, A = Affluence, T = Technology) model which has been extensively employed when it comes to environmental effects from population [18]. Commoner [34], Holdren et al. [35] proposed the IPAT model in the early time. After that, Dietz et al. [36] developed STIRPAT model based on the IPAT. Extensions of the original model include extended static and extended dynamic ones. Extended static model introduces population elements and controlled variables into original IPAT model [37]. Extended dynamic model takes lags into consideration based on extended static model [37]. Dynamic models perform usually better than other models.

Two aspects deserve notice when using STIRPAT model. First is choosing specific type of objects. Accurately, there are five types of research objects in the existed literature: Single province, single area with several provinces, representative provinces among one nation, single nation or crossed countries. Wang et al. [38] selected Guangdong province while Wang et al. [39] chose all of China's provinces except Tibet. Zhu et al. [25] chose macro-level data of China from 1978 to 2008. Wei et al. [40] affirmed the significant relationship between age structure of labor force and carbon emissions within the data of the United States, Europe, China and Japan. According to the objects' requirements, single ones [41,42] use time series data while multi ones [12,16] use panel data. Although researchers stand on different points with various objects, all of these studies reach a consensus that environmental effects from population dynamics should not be neglected.

Second, there exist diversities in choosing impact factors. According to the objectives of different models, there are mainly three kind of indicators. They are demographic indicators, affluence indicators and technology indicators. Demographic indicators include population scale, age structure [13], urbanization rate [12], employment structure, etc. Affluence indicators include GDP growth rate [42], consumption level, income level *per capita*, etc. Technology indicators include carbon intensity (carbon emission per GDP), proportion of service sector, etc. Energy consumption structure, FDI (foreign direct investment) level, opening trade level and time trend are often controlled for capturing other effects considered.

Considering the data availability, this study uses relatively macroscopic indicators to describe population characteristics. Additionally, age structure's impacts are indirect [12]. So, this study assumes that demographic transition has a direct effect on household energy consumption, and the carbon emissions can be calculated according to the conversion factors from physical unit to coal equivalent and emission factors. That is to say, energy consumption's changing trend determines the tendency of carbon emissions. Besides, household energy consumption accounts for large parts of total energy consumption. As a result, this article chooses household energy consumption as dependent indicator to reach more intuitive conclusions.

In conclusion, there are two kind of problems in existed literatures. First, research with continuous data is necessary for existed studies which usually use the data in specific year. When it comes to the data of 2015, most researches ignore policy changes on family planning. There have been significant policy changes since 2015. But existing data is not enough to support a more specific research on new trends with the executive of new policies. Second, most models in the literature are static, dynamic research is lacked. To deal with problems mentioned above, this study collects 30 provinces' data from 2005 to 2016 (Tibet excluded). It makes both a static and a dynamic analysis with comparisons between them.

3 Methodology and Data

3.1 The Model

On the basis of static panel analysis, lags of dependent variable are introduced into the model to reflect dynamic hysteresis. Before static regression, a series of tests should be done to help choose appropriate method. When it comes to dynamic regression, traditional OLS method will lead to biased and inconsistent result. Considering that problem, this study brings in pre-energy consumption to reflect consumer inertia and use GMM method to avoid the dilemma.

According to existed researches, HEC can be affected by population characteristics (i.e., population size, demographic structure, demographic changes), economic (i.e., macroeconomic growth, family income and expenditure), technology (i.e., energy intensity), lifestyle. Combined with STIRPAT model, this article assumes that lifestyle could be influenced by demographic transition whereas past demographic structure changing decides how population size and future structure changeing. Researching on these dynamic relations is beneficial to make household energy consumption changes foreseeable. The purpose of this study is to identify how demographic transition affects household energy consumption. Taking into consideration of heteroscedasticity or other factors, several elements are introduced in. STIRPAT model's normal form is $I = aP^bA^cT^de$, P, A, T represent population scale, affluence level, technology separately. a, b, c, d , stand for unknown parameters, a scales the model, b, c and d are the exponents of P, A and T , respectively. e is random disturbance. Considering the explanation problem, logarithmic form of the model is presented in Eq. (1).

$$\ln I = \ln a + b \ln P + c \ln A + d \ln T + \ln e \quad (1)$$

This study incorporates demographic structure elements with the formula above to analyze the effects comprehensively. The extended formula is shown in Eq. (2).

$$\ln hec_{it} = \ln \beta_0 + \beta_1 age_{it} + \beta_2 gdp_{it} + \beta_3 \ln rcl_{it} + \beta_4 \ln hs_{it} + u_{it} + \varepsilon_{it} \quad (2)$$

hec represents household energy consumption, age represents demographic structure including CDR and ODR, gdp represents economic growth, rcl represents residential consumption level, and hs represents household size. There is also non-observable effects u and disturbance ε in the formula. Subscript i, t represents province or city and specific year. In Eq. (2), residential energy consumption and demographic structure are dependent variable and independent variable separately, economic growth, regional residential consumption level and household size are controlled variables.

During the empirical research, the data used belongs to panel data. So, we construct a fixed effects model and random effects model shown in Eqs. (3) and (4), respectively.

$$\ln hec_{it} = \ln \beta_0' + \beta_1' cdr_{it} + \beta_2' odr_{it} + \beta_3' gdp_{it} + \beta_4' \ln rcl_{it} + \beta_5' \ln hs_{it} + u_i' + \varepsilon_{it}' \quad (3)$$

$$\ln hec_{it} = \ln \beta_0' + \beta_1' cdr_{it} + \beta_2' odr_{it} + \beta_3' gdp_{it} + \beta_4' \ln rcl_{it} + \beta_5' \ln hs_{it} + u_{it}' + \varepsilon_{it}' \quad (4)$$

Heteroscedasticity comes from two parts: First, there exist other elements beside independent variables included; second, variance of disturbance changes along with independent variable. Because of nationwide data, different samples vary a lot beside explanatory variables. In order to solve this problem, here use logarithm analysis. Additionally, consuming behavior can be affected by past consuming habit, so here introduce explained variable's lag $hec_{i(t-1)}$ as independent variable and set up dynamic panel model:

$$\ln hec_{it} = \ln \beta_0' + \beta_1' \ln hec_{i(t-1)} + \beta_2' cdr_{it} + \beta_3' odr_{it} + \beta_4' gdp_{it} + \beta_5' \ln rcl_{it} + \beta_6' \ln hs_{it} + u_{it}'' + \varepsilon_{it}'' \quad (5)$$

3.2 Data

Population structure data, residential consumption level, regional GDP growth data and household size all come from China statistical yearbook; household energy consumption data (except Tibet) comes from regional statistical yearbook; some provinces' residential consumption data are lacked, here they are filled up by calculation according to the China energy statistical yearbook and conversion factors from physical unit to coal equivalent. Only paying attention on the magnitude of data, there exist mistakes in 2003 and 2004. Considering the data availability and accuracy, this study selects nationwide data from 2005 to 2016. This is a short panel data and the time horizon is 12. It is far smaller than sample quantity so neither unit root test nor co-integration test are needed. Definition and descriptive statistics of all the variables (2005–2016) are shown as below [Tab. 1](#).

Table 1: Summary statistics of core variables

Variables	N	Mean	Std. dev.	Minimum	Maximum
Child-age Dependency Rate (CDR, %)	360	23.38	6.83	9.64	44.65
Old-age Dependency Rate (ODR, %)	360	12.74	2.46	7.44	20.04
Growth Rate of GDP (GDP, %)	360	11.30	2.97	−2.50	23.80
Household Energy Consumption (HEC, 10,000 tons of standard coal)	360	1265	790.60	55.52	4857
Residential Consumption Level (RCL, CNY)	360	12738	8113	3140	49617
Household Size (HS, person)	360	3.116	0.336	2.33	4.49

Based on the data collected, this paper chooses Beijing (BJ), Hebei (HEB), Shanxi (SX), Guangdong (GD), Henan (HEN), Guizhou (GZ), Xinjiang (XJ) and Hainan (HAN) these 8 places as representative regions to display how these variables change during past 12 years from 2005 to 2016. Because of cold climate, Beijing and Hebei consume a lot of energy for their heating demand in winter. Shanxi is the major coal production region of China. Guangdong is an area whose light manufacturing and service industries are relatively developed compared with others. Henan is a major agriculture province which belongs to central plain. Guizhou is a less developed province which locates in west of China. Hainan consume relatively less energy compared to others because of its small amount of population and limited resources. Xinjiang is a much more multi-ethnic area whose population policies are relatively different. Out of the consideration of geographic places, representative regions are located around China. And also, these regions include different types of industries or businesses and so as their developments are uneven.

According to [Figs. 1](#) and [2](#), residential consumption levels and household energy consumption of 8 provinces are increasing within these years. Residential consumption levels of Beijing and Guangdong are ahead of other provinces or cities. When it comes to household energy consumption, increasing trends of 8 provinces are relatively gentle.

4 Results and Discussion

4.1 Descriptive Analysis

In order to display how child-age dependency ratio (CDR) and old-age dependency ratio (ODR) change in China, changes of CDR and ODR in these regions from 2005 to 2016 are illustrated in [Fig. 3](#). CDRs have been descending slowly during past 12 years. This means the number of child-age who needs to be raised per 100 labors continues to decline. Among those, Guizhou, Hainan, Guangdong, Shanxi these 4 regions' CDRs appear to be decreasing yearly while other 4 regions experienced a few years' declining and then edges up slowly and slightly since 2011 because of fertility policy changing. Since this year, families can apply for a

second child if they can meet some specific qualifications. And since 2014, the second child policy is further liberalized so we can see a small increase around that time in all 8 provinces. Meanwhile, ODRs present to be ascending with different extents on the whole except a few years' fluctuation in 2005. And that means the number of old-age who needs to be cared per 100 labors continue to rise. It is obvious that China has been experiencing structural change during past decades. Since second child policy has been executed without limits, the age structure will change especially child-age dependency rate. As a result, there exists necessity to study on the relationship between population structure and household energy consumption. Related researches can support to cope with difficulties under the economic and environmental pressure leaded by population transition.

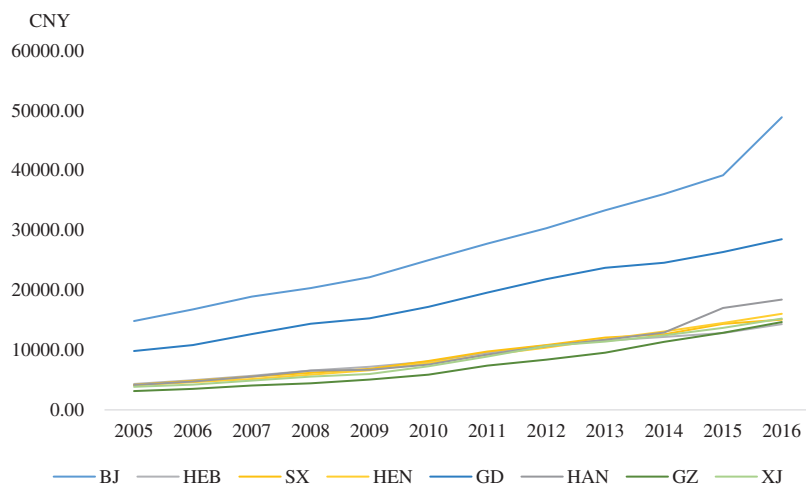


Figure 1: Residential consumption levels of 8 representative regions

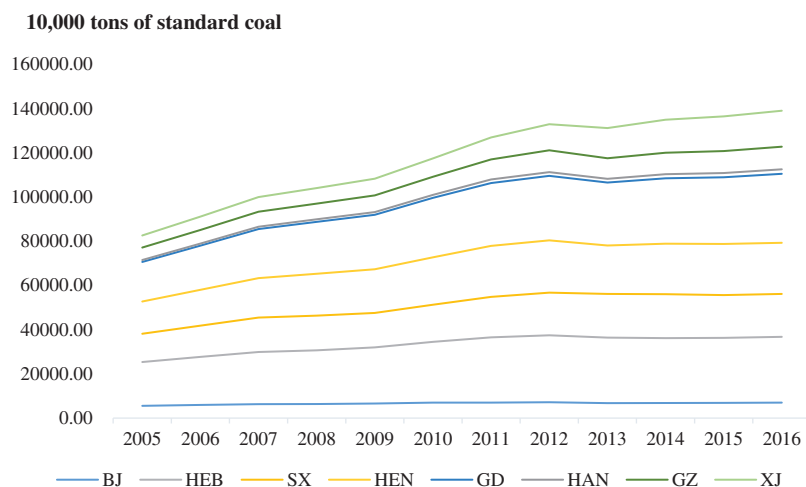


Figure 2: Household energy consumptions of 8 representative regions

Then, scatter plots of CDR and household energy consumption, of ODR and household energy consumption are utilized to recognize whether they are related. Conditions of 8 provinces selected above are presented in Figs. 4 and 5. It presents that household energy consumption has been rising during these years. Old-age dependency rate has been growing with the increase of HECs. It preliminary indicate

that ODR may have a positive impact. This means that with the increase of aging population in the future, HEC may rise further. However, the trends of child-age dependency rate and household energy consumption behave differently among 8 regions. Beijing, Hebei, Henan, Xinjiang these 4 places' CDR grow with the increase of consumption. While Shanxi, Guangdong, Guizhou, Hainan these 4 provinces change reversely. In order to explore this contradictory phenomenon, we are going to make specific research on these 8 provinces beside integral analysis of 30 provinces.

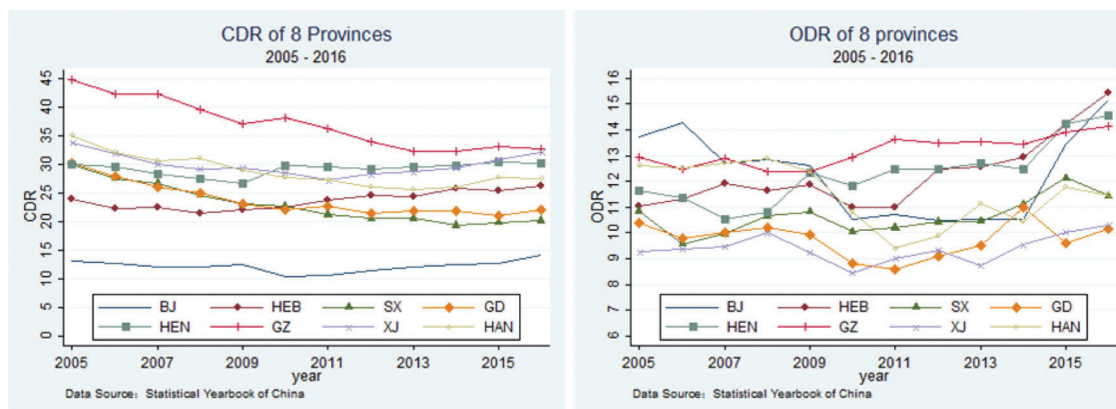


Figure 3: CDRs and ODRs of representative regions

4.2 Household Energy Consumption with Population Aging in the Whole Country

We first make an empirical analysis in the whole China. First, take individual effect tests and time effect tests of HEC, CDR, ODR, GDP growth rate, residential consumption level and household size's log value. The results indicate that, both fixed effect model and random effect model estimate better than pooled OLS model.

Then, Hausman test is taken to choose the better one between fixed effect model and random effect model. Actually, Hausman test compares estimated differences between two models, the original hypothesis is that if individual effect is random, the estimated results should be similar to each other. According to the test, the result rejects the original hypothesis at 1% significance level. So, here fixed effect model is chosen. As a reference, [Tab. 2](#) list out 3 types of regression results.

According to the static regression results with model (3), at a significant level of 5%, ODR, residential consumption level and household size pass the test while CDR and economic growth rate fail. Among them, the estimated coefficient of ODR is -0.435 , this indicates that the HEC would change in the opposite direction with the change of ODR. Specifically, one percent decrease of ODR would raise HEC by 0.435%. CDR has a positive impact on household energy consumption. Specifically, HEC would increase by 0.143% with one percent increase of CDR. The absolute value of coefficients of ODR is three times as CDR. This situation indicates that ODR affect HEC more deeply than CDR. The coefficients of the residential consumption level and household size are 0.582 and 0.642, respectively. This means every 1% increase of residential consumption level and household size can lead to 0.582% and 0.642% increase of HEC.

However, individual behavior is partly determined by past behavior. Consuming behavior could be vulnerable to the habit. So, HEC of previous period is introduced to reflect consuming habit. Dynamic model is then used with panel data. In order to deal with the endogenous problem, GMM regression is conducted to estimate.

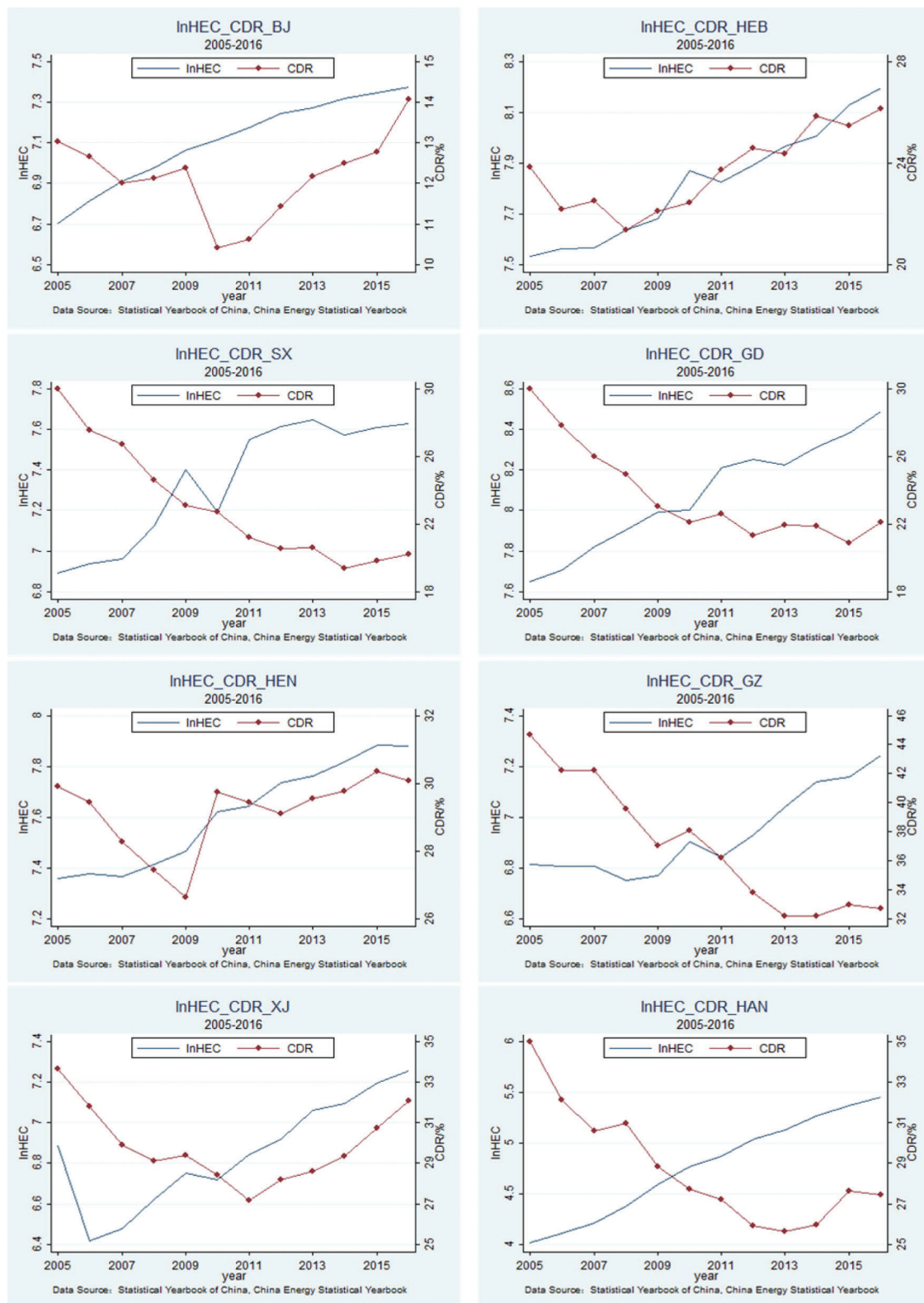


Figure 4: Household energy consumption and CDR of representative regions

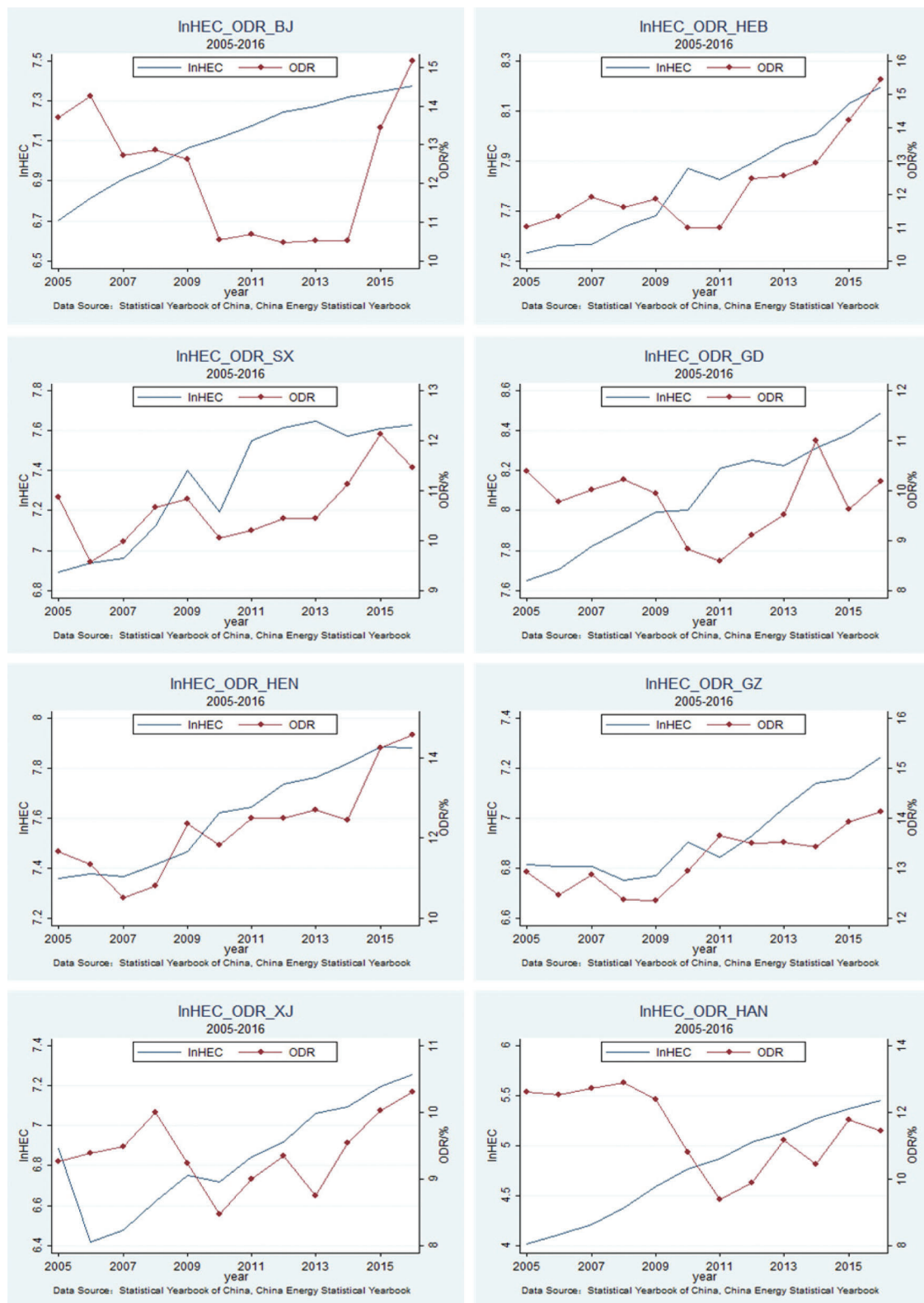


Figure 5: Household energy consumption and ODR of representative regions

Table 2: Static regression results

Variables	OLS	FE	RE
lnCDR	0.055	0.143	0.121
T-Statistics	0.26	1.40	1.20
Std.Err	0.213	0.102	0.101
lnODR	0.926***	−0.435***	−0.405***
T-Statistics	3.49	−5.21	−4.86
Std.Err	0.265	0.083	0.083
lnGDP	−0.410***	−0.041	−0.040
T-Statistics	−2.77	−1.01	−0.98
Std.Err	0.148	0.041	0.411
lnRCL	0.086	0.582***	0.575***
T-Statistics	0.77	19.55	19.28
Std.Err	0.112	0.030	0.298
lnHS	−2.020***	0.642***	0.581***
T-Statistics	−2.80	3.08	2.79
Std.Err	0.721	0.208	0.209
Constant	6.852***	1.517**	1.647***
T-Statistics	4.46	2.47	2.62
Std.Err	1.536	0.614	0.628
Observations	360	360	360
R-squared	0.223	0.779	0.779
Number of pro		30	30

Note: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

First, a differential GMM model is constructed. The prerequisite of using this model is that there is no autocorrelation in the disturbance term. The test results show that there exists first-order autocorrelation but no second-order autocorrelation in the difference of the disturbance term. Therefore, the null hypothesis “no autocorrelation” is accepted. Since 61 instrumental variables are used in the differential GMM, an excessive recognition test is required. The test results show that the null hypothesis “all instrumental variables are valid” cannot be rejected.

Then system GMM model is also used for estimation. The autocorrelation test result of the disturbance term shows that there is a first-order autocorrelation in the difference of the disturbance term. But there is no second-order autocorrelation. The over-recognition test also shows that the original assumption, namely all instrument variables are valid, cannot be rejected. This means that the instrument variables are all valid. The results of the two GMM regressions are shown in [Tab. 3](#).

Combining the results of dynamic regression with [Eq. \(3\)](#), differential GMM model, and system GMM model, here is detailed analysis. According to the differential GMM results, the HEC of previous period, residential consumption level and household size all have a significant effect on the dependent variable at 1% confidence level. ODR has a significant impact on HEC at 5% confidence level. Also, growth rate of gross regional production does not affect HEC significantly. However, in the system GMM model, all

variables have a significant effect on HEC. As we can see, estimations in SysGMM model are more significant than those in DiffGMM model. Besides, the systematic GMM model could reduce the potential errors and inaccuracies of the differential GMM estimation method. Therefore, this paper focuses on analyzing the systematic GMM estimation results.

Table 3: Dynamic regression results

Variables	DiffGMM			SysGMM		
	Coefficient	Standard Error	Z Statistics	Coefficient	Standard Error	Z Statistics
L.lnHEC	0.567***	0.030	18.70	0.794***	0.027	29.19
lnCDR	-0.082*	0.044	-1.89	-0.255***	0.042	-6.11
lnODR	-0.076**	0.039	-1.93	0.080***	0.016	5.05
lnGDP	0.016	0.015	1.09	0.041***	0.007	5.58
lnRCL	0.250***	0.013	19.49	0.118***	0.016	7.22
lnHS	0.291***	0.054	5.37	0.345***	0.035	9.92
Constant	0.787***	0.220	3.58	0.463**	0.214	2.16

Note: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

In this model, all variables pass Z test at 1% confidence level. Estimated coefficient of CDR is -0.255. It indicates that CDR and HEC change oppositely, and 1% decrease of CDR would increase HEC by -0.255%. However, estimated coefficient of ODR is 0.080 and this means HEC increasing with ODR together. Each percent increase of ODR leads to 0.080% increase of HEC. Besides, former period of HEC increases 1%, HEC of current period increases 0.794%. Growth rate of GDP, residential consumption level and household size all affect HEC positively. Each percent of increase can lead to 0.041%, 0.118% and 0.345% respectively. Among all these elements, effects from former period of HEC is the biggest. Effect from CDR is larger than economic growth and residential level. Effect from ODR is not large. The possible reason is lag effect of age-structural change. Before 2000, China has large proportion of labor age population. However, during these years, China has been transferring into aging society gradually. As this process carries on, impact of the ODR on household energy consumption will also increase in the future. Also, speed of CDR decreasing is much faster than that of ODR increasing, this maybe the reason that impact of CDR is larger than ODR.

There are several conclusions from above analysis in the perspective of the whole country. First, demographic transition affects household energy consumption significantly. CDR affect HEC negatively while ODR affect it positively. Under the condition that CDR changes more quickly than ODR, the rate of labor age population still increases. This makes residents consume more besides basic requirements. Air conditioning, personal computers and other energy-intensive goods come into normal families. This would result in larger household energy consumption. What should be mentioned is that, family planning policy started from 1970s has two functions. One is suppression effect of population emerging. This effect provides support for 30 years of development. The other is that low fertility makes that support becoming weak gradually. Now, impact from ODR is limited, but in the future, it will become larger with aging society. The second conclusion is that effects from demographic transition are larger than economic growth. Economic growth can be an important element for energy consumption. However, this may more happen in industrial production. At the same time, China has already gone into post-industrial era, a lot of energy saving actions and low carbon policies have been implemented. As a result, effect from economic growth is not that big. Demographic transition affect household energy consumption more

severely. Third, household energy consumption exists hysteresis. Quantity of former consumption affect current HEC heavily. It is understandable because behavior of consumption can continue with little changes.

The general conclusion from above analysis is that both CDR and ODR can affect HEC. However, there exist some similarities and also differences between fixed effect model and systematic GMM model. Both effects from residential consumption level and household size are positive. This somewhat indicates that wealthier and bigger households consume more energy.

There are disparities between results of dynamic and static models. It is intriguing that in the estimation results of the fixed effect model and system GMM model, the effects of CDR and ODR are in the opposite directions. To be more specific, in the fixed effect model, CDR has a positive effect while ODR has a negative effect. In the system GMM model, the effect of CDR is negative and that of ODR is positive. However, the latter estimation results are basically more consistent with results obtained from descriptive analysis. To some extent, the HEC reflects specific lifestyles of different families. Generally, sudden changes in lifestyle rarely occurs. The significant effect from lag of household energy consumption in systematic GMM regression results means that autoregression of dependent variable is neglected in static model. Furthermore, with the estimation of the system GMM model, all explanatory variables pass significant tests. Especially, regional economic growth rates should have a significant impact, which is in line with the results of Zheng & Wei (2019). It implies that both macroeconomic and microeconomic development conditions have impacts on household energy consumption. Compared with household consumption levels, regional GDP growth rate is a relatively macro indicator. Therefore, the estimation results of the dynamic model are more in line with reality.

4.3 Household Energy Consumption with Population Aging in Different Regions

As mentioned before, trends of CDR in 8 representative regions are in the opposite directions. To get more information, this study conducts regression on representative regions, respectively. The results are shown in [Tab. 4](#).

Table 4: Estimated results of representative regions

	BJ	HEB	HEN	XJ	SX	GD	GZ	HAN
L.lnHEC	0.278**	-0.160	-0.042	-0.360	0.016	-0.242	0.164	0.878**
CDR	0.003	0.006	0.029**	0.100	-0.049	0.009	0.015	-0.018
ODR	-0.014*	0.046	-0.004	-0.141	-0.019	-0.016	0.070	0.004
GDP	-0.006	0.021	-0.008	-0.006	-0.008	-0.010	-0.026	-0.007
lnRCL	0.327***	0.649**	0.401***	0.752**	0.232	0.949**	0.273	-0.008
Constant	2.015***	2.282*	3.607***	0.956	6.535	0.774	2.254	1.317

Note: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

According to the results, lag of HEC in Hainan affects current consumption to greater extents than other elements. And under most circumstances, residential consumption levels affect household consumption a lot compared to other factors.

According to [Fig. 3](#), Beijing has lowest CDR and highest ODR from all 8 provinces while Xinjiang has the highest CDR and lowest ODR. Beijing's household energy consumption is mainly affected by last period consumption while Xinjiang is mostly influenced by residential consumption level. Combining with former descriptive analysis, Guizhou's CDR is high but its effect on HEC is small. Guizhou's ODR is relatively low but its influence is quite significant. Generally speaking, in relatively more developed regions, previous

period HEC would have larger effects on current HEC. Meanwhile, Residential consumption level's effect on HEC would be larger in less developed regions. To a general speaking, influences from CDR and ODR are smaller than other elements in these regions except Shanxi.

Among representative provinces, there exists difference in the driving factors of HEC among different regions. Some northern provinces including Beijing, Hebei, Xinjiang and Shanxi, families in these regions consume a lot in winter with the format of central heating by units of houses. With the shrinking of family scale, the number of houses increases. As a result, HEC increases with CDR increasing. Among these regions, effects from demographic transition on Beijing are the smallest. Maybe demographic transitions are not driving factors for household energy consumption in Beijing. Moreover, CDR has a negative effect on HEC in Shanxi while ODR has a positive effects in Hebei. According to Fig. 3, Hebei's ODR is higher than most regions. With population aging, the scale of family is also shrinking, household consumption in Hebei can be affected by ODR to a large extent. HEC of Shanxi is more influenced by residential consumption level, maybe effects from RCL cover most effects from demographic transitions.

In order to compare these regions and find their differences intuitively, this study made radar graph in accordance with 5 driving factors of HEC. Combining Figs. 1, 2, and 6, HECs in developed regions are not highly affected by demographic transition but by previous period energy consumption and residential consumption level, e.g., Beijing and Guangdong. Because of this, demographic transition affects household energy consumption little.

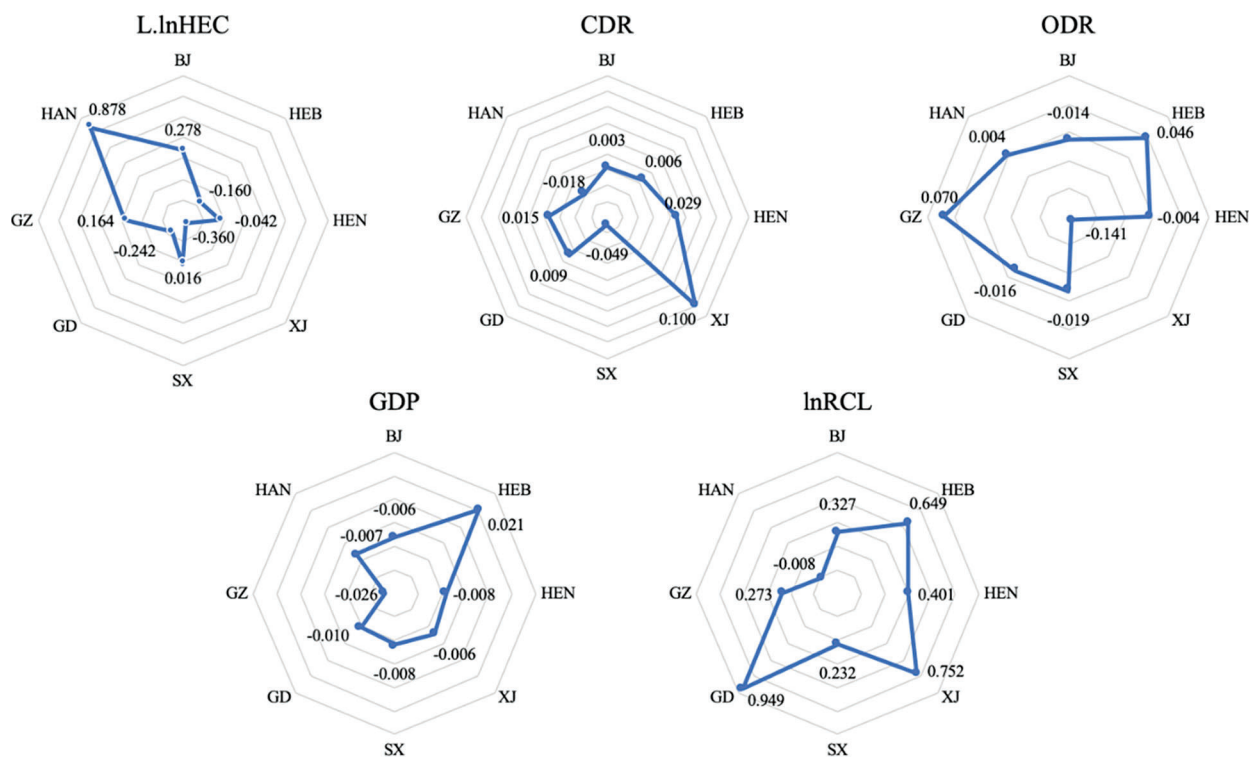


Figure 6: Driving factors of household energy consumption of representative regions

At the same time, HEC in less developed regions are highly influenced by CDR and ODR, e.g., Guizhou. As in this kind of region, residents spend on household energy only to meet their basic living requirements. As a result, the scale of household decides their corresponding energy consumption. At the

same time, Guizhou has both high CDR and ODR, this means more people in one family. As a result, this region's household energy consumption will increase. Additionally, the low technical levels of energy consumption and energy saving make HECs in Guizhou easily affected by demographic transitions.

Combining with Fig. 3, Regions with large population can be more easily affected by demographic transition especially by CDR, e.g., Henan. Both ODR and CDR of Henan are relatively higher than other regions. Families in these regions seem to be hard to change their lifestyle in a short time. It takes a long time to change population structure in these regions. As a result, their lifestyle remains still with similar household energy consumption structure and volume. From the long point of view, larger CDR can evolve into larger labor population. This can bring families more income and as a result, the household energy consumption will increase based on higher income level.

5 Conclusions and Policy Implications

This study analyzes demographic transition's influences on the household energy consumption in different provinces or cities in China. Data including household energy consumption, age structure, residential consumption level, etc. from 2005 to 2016 is collected. An extended STIRPAT model with CDR and ODR is constructed. Both static and dynamic regression analysis are performed using the fixed-effects model and system GMM model respectively. To investigate the heterogeneities among different regions, regressions on representative regions are conducted. The results generally indicate that age structure of the population has a significant impact on household energy consumption.

Based on dynamic regression results, the child-age dependency rate has a negative effect on household energy consumption. This implies that along with children need to be raised getting fewer and fewer, household energy consumption will increase. The possible reason is that as the dependency rate of children declining, the proportion of the working-age population gradually increases. This would increase the income of residents. Meanwhile, people would spend more to gain better home-stay experiences without the burden of children. That may gradually change the structure of household energy consumption, making some high energy consumption devices become more ordinary households. These high energy cost appliances undoubtedly can consume energies more intensively. Although China has adjusted its family planning policy in 2015, the effect of the comprehensive second-child policy is not as expected due to people's fertility concepts changing. It takes time to know that how will the children's dependency rate in the next few years lead to energy consumption.

Old-age dependency rate has a positive influence on household energy consumption. This implies that accompanied with population aging, household energy consumption will increase. The main reason is that as the dependency rate of the elderly increases, the use time of various consumer goods in the family will be greatly extended. It indicates that living energy demand will be increased. At the same time, the average life expectancy of the population is continuously increasing, and the aging trend will become more obvious. The current increase in the old-age dependency rate has a limited impact on living energy consumption. With the further aging of our population, the effect of that on living energy consumption will gradually increase in the future.

Using both CDR and ODR to catch the main demographic transitions can also reflect the raising burden in a household. Moreover, uncoordinated burden of families can convert to social burden. In dynamic regression model, lag of current household energy consumption can reflect the reality more precisely. Based on the comparison between static and dynamic models' results, without considering lag of household energy consumption can lead to autoregression problem and then misestimated effects from demographic transition. Results in dynamic regressions are more reliable. Effects from the whole country perspective and regional perspective are relatively different. Besides whole situation in China, regional differences are also investigated because of China's vast territory. This can not only provide reference for the whole country, but also provide an idea for provinces to conduct a survey before make policies.

Energy saving should be the object of policies but that cannot be based on the decline in living standards. Considering the demographic transition in China, the impact of changes in the child-age dependency rate and the old-age dependency rate on household energy consumption will gradually increase. This also means the rate of labor decreasing. Under this situation, people will not be able to pay for high energy efficiency appliances which are often associated with high price. When formulating population policies and energy consumption policies, their effects should be organically combined together to continuously optimize the household energy consumption structure according to changes in the age structure. Meanwhile, considering the labor lack condition in future China, government may do more changes about fertility policy and constructions of public service system. For example, government can consider cancelling the limit of fertility and let couples make decisions of raising how many children. At the same time, high old- dependency rate can lead to long time of home stay. Out of the purpose of energy saving, more public instruments should be installed in communities, so that elder can allocate more time in these public places which can provide cooling and heating function. Due to the significant impact of previous period household energy consumption level, the implementation of current sustainable energy development policy should be emphasized in long-term strategies. For example, better fare policy of household energy consumption should be implied to help shape environment friendly energy using habits.

Due to the lack of data after 2016 when population policy was significantly changed, the influences of CDR after 2016 could not be revealed in this study. Also, under the rigorous situation of population, the government may make big changes of fertility policy in the near future. Considering that life expectancy is increasing, the retirement may be delayed. If this happens, the structure of population can change a lot. So, demographic impacts on household energy consumption are still worth researching. Further study can get an insight into the effects of CDR and ODR with the policy changes. At the same time, what cannot be neglected is that large amounts of people migrate from inland to provinces or cities along with east coast. Under this background, population structure transition and their impacts on household energy consumption deserves further study. Meanwhile, this study only pays attention to the total amount of household energy consumption. As the volumes of population, economy and other characteristics of representative regions are different, may be paying attention to the energy consumption per household can lead other valuable results. This kind of research is worth doing in the future.

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