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Original Research

Threshold Effect of Urbanization Level on Household Energy Consumption in Beijing-Tianjin-Hebei Region

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Abstract

The Beijing-Tianjin-Hebei (BTH) region is an important economic center of China but has the problem of severe environmental pollution. Urbanization prompts the household energy consumption growth and then deteriorates the environmental conditions in this region. Based on panel data of the BTH region from 2000 to 2017, this research uses a dynamic threshold model with per capita disposable income as the threshold variable to investigate the non-linear impact of urbanization on household energy consumption. The empirical results show that: 1) In the process of urbanization, per capita resident disposable income has a significant threshold effect on household energy consumption, and their relationship presents an inverted U-shaped trend. 2) The change of household energy consumption habits can significantly improve the household energy consumption level. 3) Industrial structure adjustment, urban population density, and education level of residents have restraining effects on household energy consumption growth. 4) Technical advance and GDP per capita growth opposite effects. The empirical analysis also shows that the regional government can consider increasing the disposable income of the residents in Hebei Province to alleviate the imbalance in energy consumption. At the same time, efforts should be made to develop high-tech industries and high-end service industries, and adopt a more intensive urban planning development model to increase urban population density.

Keywords: Beijing-Tianjin-Hebei region, urbanization, household energy consumption, dynamic panel threshold model

Introduction

Since the 21st century, China's economy has developed rapidly, and people's living standards have also increased substantially. In 2000, China's GDP was 10 trillion yuan, and by 2017 it had increased to 82 trillion yuan [1], an increase of more than 8 times. The Beijing-Tianjin-Hebei (BTH) region is a key area of China's economic development, and its GDP accounts for more than a quarter of China's GDP. Along with the rapid economic development, China's population urbanization process has also continued to advance, and the urbanization rate of the permanent population increased from 36.22% in 2000 to 58.52% in 2017 [1].

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From this trend, China is very likely to complete the target of 60% of the urbanization rate of the permanent population in the National New Urbanization Plan (2014-2020) by 2020. The rapid advancement of urbanization and the urgent need to build a new type of urbanization will directly lead to changes and adjustments in the energy consumption structure, and household energy consumption has become the second largest energy field after the industrial field [2-4]. According to the calculation method of electrothermal equivalent, household energy consumption was 11,0769,100 tons of standard coal in 2000, and 414,461,600 tons of standard coal in 2017 [5], which increased by about 3.74 times in 17 years. With the acceleration of China's urbanization process, urban agglomerations have become the core of human settlements and economic development [6, 7]. The BTH region is the most important region in the process of urbanization in China [8, 9]. The urbanization rate in this region has been increasing since 2000. Among them, Hebei Province has a larger growth rate, followed by Tianjin City, and Beijing has remained stable after 2010. However, in general, the urbanization rate of Beijing, Tianjin and Hebei is still on the rise.

Urbanization has brought a series of challenges and pressures to natural resources and the ecological environment. In particular, the contradiction between energy supply and demand has intensified, and environmental pollution has become increasingly prominent [10-12]. Taking into account energy security and air pollution issues, there is no doubt that energy consumption will be a new constraint on the economic development and urbanization process in the BTH region [13-15]. Therefore, it is very necessary for energy companies to introduce or propose new technologies or innovative solutions in their development strategies [16]. At the same time, better use of solar power to improve the efficiency of solar power can also relieve energy pressure and environmental pollution caused by energy consumption to a certain extent [17, 18]. "Urban Blue Book: China Urban Development Report No. 10" pointed out that the BTH region is still the region with the worst air pollution in the country. Compared with the Yangtze River Delta region and the Pearl River Delta region, air pollution in the BTH region is particularly serious. The urbanization process in the BTH region will exert increasing pressure on future energy consumption, and energy consumption is the main source of air pollution in the region, and household energy consumption is the most important part of energy conservation [19]. Governments around the world once put the focus of energy demand management on industrial energy use, but with the acceleration of urbanization and the improvement of residents' living standards, the energy consumption of urban residents is increasing. In some developed countries, residential energy consumption has exceeded industrial energy consumption. According to statistics, household energy demand in EU countries exceeded industrial energy demand in the 1990s [20]. The proportion of household energy consumption in the BTH region's energy consumption has continued to rise from 2007 to the present. Among them, Beijing has been an upward trend from 2000 to the present. Tianjin has a large fluctuation and there is no stable long-term trend. The overall trend in Hebei and BTH region is about the same. With the acceleration of China's urbanization process, the energy consumption of Chinese residents will continue to grow in the future. This trend development of energy consumption and the evolution of energy consumption structure may repeat the path of industrialization and urbanization in Western countries and become a new growth point. This also means that household energy consumption and energy consumption structure cannot be ignored. It is particularly important that the formulation of future energy policies needs to be more inclined to the consumption field. Therefore, to better understand the relationship between urbanization and household energy consumption in the BTH region, and to solve the problem of energy sustainable development strategy in the process of urbanization, is an important link to achieve sustainable social and economic development.

Although urbanization and energy consumption of BTH region have attracted the attention of many scholars, the research mainly focuses on the following three aspects: 1) The impact of urbanization. In the BTH area, due to the economic model of high energy consumption, high pollution, and high emissions, many environmental problems have emerged [21]. At the same time, although the rapid urbanization process has significantly improved the living standard of residents, it also aggravates the environmental pollution and the demand for energy resources in BTH region, threatening the sustainable development of the region [22]. 2) The impact of energy consumption. The energy consumption and air pollution in the BTH region are spatially correlated [23]. Without strict energy and industrial structural adjustments, even the most advanced terminal technology cannot make BTH region reach the target of 35 $\mu g/m^3$ of annual PM2.5 emission concentration by 2030 [24]. 3) The relationship between urbanization and energy consumption. Zhang [25] used STIRPAT model to study the impact of urbanization on total energy consumption in Beijing from 1980 to 2011, and the results showed that population size, population density, population urbanization rate, per capita GDP and technological progress are positively correlated with total energy consumption. Yang [26] also used STIRPAT model to study the impact of population urbanization on energy consumption and regional differences in BTH region, and found that urbanization rate had a significant positive impact on energy consumption, but the degree of impact was in order of Beijing, Tianjin and Hebei. The variables of urban population and per capita GDP have a significant positive impact on energy consumption in Beijing, Tianjin and Hebei, while energy intensity has a significant negative impact on total energy consumption.

Population size and urbanization rate are the main factors affecting the total energy consumption in BTH region. Urban per capita GDP and energy intensity have a small impact on energy consumption. Wang [27] found that the urbanization rate of Beijing, Tianjin and Hebei has a limited contribution to the growth of energy consumption, and the growth effect of energy consumption mainly comes from itself. These studies provide useful suggestions for guiding urbanization and energy consumption in the BTH region. Although there are some studies discussing the relationship between urbanization and energy consumption, there are certain limitations: on the one hand, they only considered the linear relationship; on the other hand, they investigated energy consumption as a whole, ignoring the differences between life and other production aspects. Therefore, this article will analyze the non-linear relationship between urbanization in BTH region and household energy consumption.

The threshold model is used most frequently in the research on the nonlinear impact of urbanization on household energy consumption. For example, the research of Yang and Wang [28] showed that urbanization has different threshold effects on residents' direct energy consumption and indirect energy consumption. Urbanization has a significant positive effect on residents' indirect energy consumption after the urbanization rate exceeds 48.33%. Yang et al. [4] used the A threshold STIRPAT model and China 's annual provincial data from 1996 to 2014 to study the impact of urbanization on residential energy consumption, and the results showed that the impact of urbanization on household energy consumption was different in different per capita income stages and urbanization stages. Yan et al. [29] based on the Hansen panel threshold regression model, using panel data from 11 provinces and cities in the Yangtze River Economic Belt from 2005 to 2015, empirically analyzed the nonlinear development between urbanization and energy consumption in the basin. The results show that the urbanization process in economically backward and developed regions is less dependent on traditional energy consumption, while regional urbanization with fast economic development has obvious promotion effect on energy consumption. Drawing on previous experience, this paper also selects the panel threshold model. On this basis, the total household energy consumption of the previous period is used as an explanatory variable to consider the current period, and a dynamic panel threshold model is established.

In summary, although domestic and foreign scholars have done more research on the impact of urbanization on household energy consumption, there are still several shortcomings. First, most domestic and foreign scholars only pay attention to the linear relationship between urbanization and residents' energy consumption. Second, in the existing nonlinear relationship, most scholars have ignored the habitual effect of household energy consumption and have not established a dynamic threshold model. The third is the choice of threshold variables. Most literature chooses urbanization as the threshold variable, ignoring the impact of different economic stages or per capita disposable income on household energy consumption. Therefore, this article is based on the research status of domestic and foreign scholars, and based on the inertial characteristics of domestic energy consumption, the Beijing-Tianjin-Hebei region is selected as the research object to establish a dynamic threshold model of urbanization on household energy consumption. And select per capita disposable income as the threshold variable to test the phased impact of urbanization on household energy consumption at different income levels. It hopes to provide theoretical support for alleviating the contradiction between urbanization and household energy consumption in the Beijing-Tianjin-Hebei region.

This paper is structured as follows: After the introduction in Section 1, Section 2 introduces the materials and methods. Section 3 presents the empirical results and discussion. Section 4 summarizes the key findings and offers policy implications.

Materials and Methods

Data Collection

In order to ensure the uniformity of the variables and the validity of the empirical results, this paper selects panel data from 2000 to 2017 in the BTH region for empirical testing. The selection results and meanings of variables are shown in Table 1.

The following provides theoretical support for the selection of variables:

(1) Explained variable: The data comes from household energy consumption items in the energy consumption of various regions in the China Energy Statistical Yearbook.

(2) Explanatory variables: The urbanization rate is calculated based on the proportion of urban permanent residents to the total permanent population. Among them, the data of Beijing come from the Beijing Statistical Yearbook of, the data of Tianjin and Hebei from 2000 to 2004 come from the "China Compendium of statistics 1949-2008", and the data after 2005 come from the China Statistical Yearbook.

(3) Threshold variable: Economic development is expressed in terms of per capita disposable income of residents. The data comes from the China Statistical Yearbook.

(4) Control variables: Urbanization not only has a direct impact on energy consumption, but also indirectly affects energy consumption through factors such as economic improvement, industrial structure changes, population size changes, technological progress drives, and human capital accumulation. Therefore, this article selects the per capita disposable income of urban

Table 1. Variable selection results and meanings.

Title 1	Variable	Sign	Variable meaning	Unit
Explained variable	Total household energy consumption	TE	Total amount of residential energy converted into standard coal	10,000 tons of standard coal
Explanatory variables	Urbanization rate	UR	Number of urban residents divided by number of residents	%
Threshold variable	Income level	INC	Per capita disposable income of urban residents	yuan
Control variable	Industrial structure	IND	Tertiary industry output value divided by regional GDP	%
	Population size	DEN	Urban population density	people/km^2
	Technical progress	RD	Research and development technology	100 million yuan
	Economic growth	PGDP	GDP per capita	yuan
	Technical progress	EDU	Average years of education of residents	year

residents to measure the level of residents' income. The proportion of tertiary industry output value to regional GDP represents the industrial structure, and the urban population density measures the size of urban population. The GDP per capita represents the level of economic growth in the region and is converted into actual values based on the 2017 base period. These data are from the China Statistical Yearbook. The intensity of Research and Development (R&D) funding represents the level of technological progress in the region, and its data mainly comes from the Statistical Bulletin of National Investment in Science and Technology. Human capital borrows from Zhu's research method [27] and uses the average years of education of residents as a measure. The specific calculation formula is:

$$Hum = Primary \times 6 + Junior \times 9 + Senior \times 12 + College \times 16$$

In the formula, Hum is the average years of education, and Primary, Junior, Senior, and College respectively represents the proportion of residents of primary school, junior high school, college and above in the population over 6 years old. Individual missing data were estimated using the mean method. Variable selection results and meanings are shown in Table 1. The descriptive statistics of the variables are shown in Table 2. It provides the names and descriptive statistics of this study's variables. This table indicates significant differences among the variables' observed values, which is possible for the following empirical estimation.

Methods

Dynamic Threshold Panel Model

At present, scholars at home and abroad have mostly ignored the inertial characteristics of household energy consumption in the nonlinear research on urbanization on household energy consumption. Therefore, this paper takes the total household energy consumption of the previous period as an explanatory variable into this period. Because the first-order lag term of the explanatory variable is used as the explanatory variable, the explanatory variable is endogenous and violates the assumption that the explanatory variable is not related to the disturbance term. Although the panel data model of fixed effect or random effect based on instrumental variable method can effectively solve the endogeneity, it is difficult to describe the characteristics of "early dependence and slow change" between explanatory variable and explained variable. While the dynamic panel data model can not only better deal with the endogenous problem, but also incorporate the first-phase lag term of the explained variable into the empirical equation, so the empirical process can effectively reflect the characteristics of "early dependence and slow change" of the explained variable [28]. In view of this problem, the generalized matrix method proposed by Blundell & Bond [29] solves the problem of bias and consistency of the estimated parameters well, and improves the accuracy of the analysis results.

Because the system GMM uses both the endogenous variable level change and the difference information, the lag term of the weak exogenous variable is used as an instrumental variable in the estimation equation to

Table 2. Descriptive statistical characteristics.

Variable	Obs	Mean	Std. Dev.	Min	Max
TE	54	103.15	64.51	29.69	295.01
UR	54	67.77	19.51	26.09	86.50
INC	54	22.29	13.52	5.66	62.41
IND	54	51.18	16.16	31.51	80.60
DEN	54	20.95	7.62	8.31	36.39
RD	54	38.79	39.68	2.47	157.97
PGDP	54	36.34	32.56	2.28	121.11
EDU	54	9.86	1.29	7.74	12.50

obtain a consistent estimate, which is more effective than the differential GMM [30], and the current application is more and more widely, so this paper chooses the system GMM for measurement estimation. However, the one-step system GMM adds the horizontal equation and increases the number of moment constraints. Therefore, Sargan test and AR test are needed to determine whether the instrumental variables are valid. In the Sargan test, the null hypothesis is that the instrumental variables are jointly valid. In the AR test, the residual term allows first-order sequence correlation, but does not allow second-order sequence correlation. The flowchart of the specific research methods after selecting the model is shown in Fig. 1.

The threshold model focuses on the stepwise change between the explanatory variable and the explained variable, and finds the key turning point and then performs segmental regression analysis. Hansen [34] proposed a non-dynamic panel threshold regression model in 1999, which provides a new measurement method for the study of threshold effects. This measurement model can estimate the specific threshold value through model regression on the one hand, and can test the validity and significance of the estimated threshold on the other hand. On this basis, this paper takes into account the lag of household energy consumption, takes the total energy consumption (TE) as the explained variable, the urbanization rate (UR) as the explained variable, and takes the per capita disposable income (INC) of urban residents as the threshold variable, and takes the proportion of tertiary industry output value (IND) and the urban population density (DEN), research and development technology funds (RD) and the per capita GDP (PGDP) as the control variables to establish a dynamic panel threshold model of urbanization on the level of household energy consumption. In order to ensure the stability of the data, the PGDP data is processed logarithmically. In order to reduce the interference of heteroscedasticity on the validity of the test, the relevant variables are all taken as natural logarithms. The model first assumes that there is a single threshold λ:

$$\ln TE_{it} = \mu_i + \alpha \ln TE_{t-1} + \beta_1 \ln UR_{it} I(\ln INC \le \gamma) + \beta_2 \ln UR_{it} I(\ln INC > \gamma) + \varphi \ln x_{it} + \varepsilon_{it} \tag{2}$$

...where μ_i is the intercept term representing individual heterogeneity, ε_{it} is the random perturbation term, INC is the threshold variable, and the control variable is x, then the coefficient matrix are:

$$\beta = \begin{vmatrix} \alpha \\ \beta_1 \\ \beta_2 \\ \varphi \end{vmatrix} \tag{3}$$

$$X = \begin{vmatrix} \ln TE_{t-1} \\ \ln UR_{it} I(INC \le \gamma) \\ \ln UR_{it} I(INC > \gamma) \\ \ln x_{it} \end{vmatrix} \tag{4}$$

The variable matrix is:

$$\ln TE = \beta^T X_{it}(\gamma) + \mu_{it} + \varepsilon_{it} \tag{5}$$

In order to estimate the parameters of the model, the influence of the individual effect μ must first be eliminated. The common method is to subtract the average value within the group from the observations of each variable, also known as decentering. The changed model is:

$$\ln TE^* = \beta^T X_{it}(\gamma)^* + \varepsilon_{it}^* \tag{6}$$

Written as a matrix:

$$\ln TE^* = X(\gamma)^{*T} \beta + e^* \tag{7}$$

The per capita disposable income of urban residents can be any given value λ in the value range of the variable. The slope β of the independent variable UR is:

$$\beta_\lambda = X^*(\gamma)^T X^*(\gamma))^{-1} X^*(\gamma)^T Y^* \tag{8}$$

The residual estimates of the regression equation are:

$$e^*(\gamma) = Y^* - X^*(\gamma)\beta_\gamma^T \tag{9}$$

Sum of the squared residuals of the regression equation:

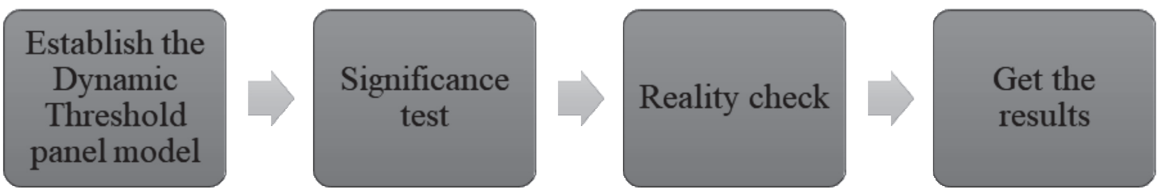

Fig. 1. Flow chart of research methods.

Table 3. The critical value for threshold authenticity test.

α	0.80	0.85	0.90	0.925	0.95
LR	4.50	5.10	5.94	6.53	7.35

$$SSR(\gamma) = e^*(\gamma)^T e^*(\gamma)$$
$$= Y^{*T}[1 - X^*(\gamma)^T (X^*(\gamma)^T X^*(\gamma))^{-1} X^*(\gamma)^T] Y^* \quad (10)$$

Choose $\hat{\gamma}$ so that $SSR(\hat{\gamma})$ is the smallest, then the threshold estimator is:

$$\hat{\gamma} = \arg\min_{\gamma} SSR(\gamma) \quad (11)$$

The above is a search for a single threshold, and so on for multiple thresholds. After estimating the threshold value and the slope value, it is necessary to further verify the significance and authenticity of the threshold effect.

Significance Test

First, it is simulated to estimate whether the parameters of the two groups of samples divided based on the threshold are significantly different to confirm whether the threshold exists. Construct the significance test null hypothesis: $H_0 : \beta_1 = \beta_2$. If this hypothesis holds, there is no threshold effect. Note that the sum of squared residuals obtained under the "$H_0 : \beta_1 = \beta_2$" constraint is SSR^* to distinguish it from the sum of squared residuals without constraints. Hansen proposed using the following Likelihood Ratio Test (LR) statistics:

$$\text{LR} = (SSR^* - SSR(\hat{\gamma})) / \hat{\sigma}^2 \quad (12)$$

...where $\hat{\sigma}^2 \equiv \frac{SSR(\hat{\gamma})}{n(T-1)}$ is a consistent estimate of the variance of the disturbance term. Because the threshold γ under the null hypothesis is uncertain, the asymptotic distribution of LR statistics is not the standard χ^2 distribution, and the critical value cannot be simulated. However, bootstrap can be used to simulate the asymptotic distribution of the original sequence, and then a corresponding P test is constructed. If the P value is less than the critical value, the null hypothesis is rejected to obtain a threshold value, and vice versa. After determining the first threshold value, a second threshold value search is needed. After determining the first threshold, it is necessary to search for the second threshold. The method of searching for the second threshold is based on the process of obtaining the first threshold, and the same is true for multiple thresholds.

Reality Check

Then determine the confidence interval of the threshold value to verify whether the estimated value of the threshold is consistent with the actual value. Assuming that the original assumption is $H_0 : \gamma = \gamma_0$, the corresponding likelihood ratio statistics are:

$$LR\ \gamma = \ SSR\ \gamma - SSR\ \hat{\gamma}\ \ ) / \hat{\sigma}^2 \quad (13)$$

It can be proven that the distribution of the statistic LR is also non-standard when "$H_0 : \gamma = \gamma_0$" holds, and $SSR(\gamma)$ takes the sum of the squared residuals of any value for the threshold variable. Hansen provides a criterion for rejection domain. When $LR > -2\ln(1-(1-a)^{1/2}$ is established, the null hypothesis is rejected, where a is a significant level, and this paper takes 5%. According to the calculation results of Hansen [35], the commonly used threshold value table is shown in Table 3.

Results and discussion

Threshold Effect Test

This paper uses STATA15.0 to test the threshold effect on the single threshold, double threshold, and triple threshold in turn, and uses the bootstrap method to repeatedly sample 1,000 times to test the significance of the threshold effect. The test results are shown in Table 4. From the F statistic and P value, it can be seen that the model's single and double threshold effects are significant, and the assumption that the double threshold model is better than the triple threshold model is not significant at the significance levels of 10%, 5%, and 1%. Therefore, the existence of the double-threshold effect was statistically affirmed, so the double-threshold was selected for subsequent empirical analysis.

Threshold Value Estimation and Authenticity Test

Table 5 shows the threshold and confidence interval estimation results in the BTH region from 2000 to 2017.

Table 4. Threshold effect test.

Threshold	F-Value	P-Value	(10%,5%,1%) Critical values
Single Threshold Test	20.16	0.0000	(13.1740, 15.2754, 15.4486)
Double Threshold Test	13.13	0.0750	(11.7579, 17.5635, 20.4656)
Triple Threshold Test	7.97	0.4850	(17.8374, 19.1120, 21.3129)

Table 5. Threshold value and confidence interval estimation results.

Thresholds	Estimated Value	95% Confidence Interval
Threshold 1	9.5968	[9.4618, 9.6574]
Threshold 2	9.9983	[9.8368, 10.0090]

The results show that the two thresholds of the model are 9.5968 and 9.9983.

After estimating the threshold value, the authenticity of the estimated threshold value needs to be tested. The test results are shown in Fig. 2.

With the help of the likelihood ratio function graph drawn in Fig. 2, we can clearly see the estimated result of the threshold value and the 95% confidence interval of the threshold value when the per capita disposable income of residents is used as the threshold variable. In the dual threshold model studied in this paper, the estimated values of the dual threshold are 9.5968 (see Fig. 2a) and 9.983 (see Fig. 2b). The LR statistic of each threshold estimate is lower than the LR statistic critical value of 7.35 at the 5% significance level indicated by the red dashed line (see Table 3). Based on this, it can be seen that the double threshold of per capita disposable income of residents is consistent with the true threshold. Therefore, according to these two threshold data, it can be divided into three types: low income (INC≤9.5968), medium income (9.5968<INC≤9.9983) and income (INC>9.9983).

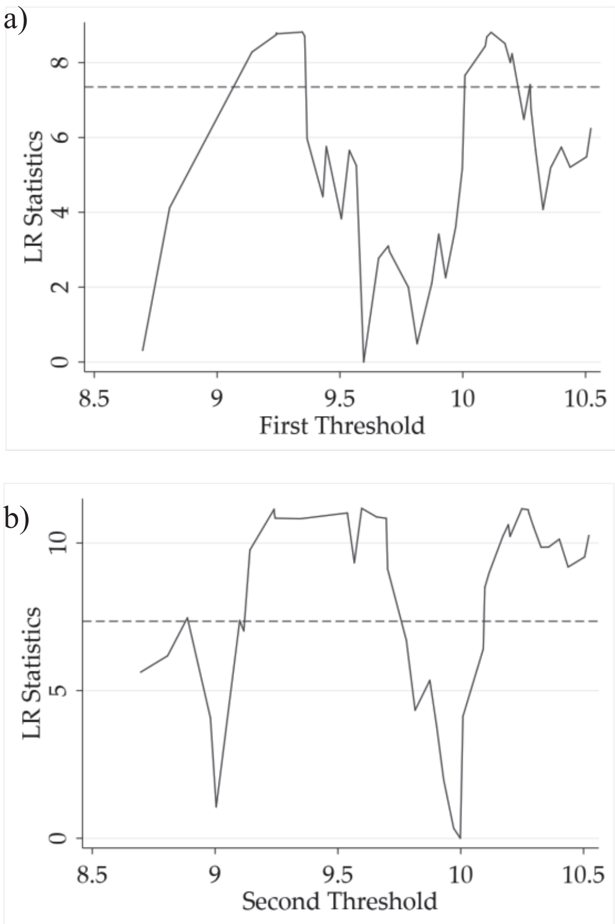

Fig. 2. LR test result.

Dynamic Panel Threshold Regression

The result of system dynamic panel-data estimation shows that the P value of this test is 0.04, and the model passed the AR test and Sargan test, indicating that the choice of tool variables was reasonable, and the regression results of the model were trustworthy. As can be seen from Table 6, the one-phase lag coefficient of energy consumption in the model is significantly positive, indicating that there is a non-linear dynamic threshold effect of population urbanization on the total residential energy consumption. The household energy consumption in the previous period has a significant positive driving effect on the current energy consumption, which is consistent with previous studies [36, 37]. The lagging effect of the urbanization rate may be due to the transformation of the rural population into the urban population. The demand for housing, infrastructure, and energy supply is not immediately manifested but a gradual process.

From the threshold effect test results, it can be seen that the impact of the level of urbanization on household energy consumption has a significant dual threshold effect on per capita disposable income. The level of urbanization generally inhibits household energy consumption, which means that the increase in the level of urbanization will inhibit household energy consumption. The elasticity coefficient presents an inverted U-shaped trend: when the per capita disposable income is less than 14,717.61 yuan, the elasticity coefficient of the impact of the level of urbanization on household energy consumption is -0.0079. With the development of the economy, the elasticity coefficient after crossing the first threshold becomes -0.0016, which is weaker than the level of urbanization at this stage in the first stage. After crossing the second threshold of 21,989.05 yuan, the elasticity coefficient becomes -0.0041. Compared with the second stage, the level of urbanization in this stage has a stronger impact on household energy consumption, but it is still lower than the first stage. To some extent, this is because the urbanization process in the economic backward and economically developed period is less dependent on traditional energy consumption, and the regional urbanization in the rapid development of the economy has a significant role in promoting energy consumption [29].

In the dual-threshold model with per capita disposable income as the threshold variable, for the control variables, the impact of residents' education on household energy consumption is significantly negative.

Table 6. Dynamic panel-data estimation.

Variable	Coef.	Robust Std. Err.	z	P>|z|	[95% Conf. Interval]
ln TE_{-1}	0.8763***	0.0150	58.3000	0.0000	[0.8469, 0.9058]
i1	–0.0079***	0.0011	–7.1200	0.0000	[–0.0100, –0.0057]
q1	–0.0016	0.0759	–0.0200	0.9830	[–0.1504, 0.1471]
p1	–0.0042	0.0097	–0.4300	0.6690	[–0.0233, 0.0149]
ln IND	–0.0746	0.1141	–0.6500	0.5130	[–0.2981, 0.1490]
ln DEN	–0.0040	0.0145	–0.2800	0.7820	[–0.0323, 0.0243]
ln RD	0.0595***	0.0119	4.9900	0.0000	[0.0362, 0.0829]
ln PGDP	0.0230	0.0234	0.9800	0.3270	[–0.0230, 0.0690]
ln EDU	–0.2777**	0.1262	–2.2000	0.0280	[–0.5250, –0.0304]
_cons	1.3151***	0.2718	4.8400	0.0000	[0.7823, 1.8478]
AR(2)				0.9468	
Sargan			0.0667	0.9833	

Note: *, **, and *** indicate the significance level of 10%, 5%, and 1% respectively; the corresponding Z statistic in (): P value corresponding to the statistic in [].

It shows that the improvement of residents' educational level can significantly inhibit the growth of household energy consumption, and has an important positive effect on reducing household energy consumption. It can be seen that it is very necessary to strengthen the education level of residents, and for some people with low education level, they can carry out community activities to popularize energy conservation and emission reduction knowledge. Industrial restructuring (the proportion of the tertiary industry is selected as an indicator in this article) and urban population density also have a negative impact on household energy consumption. It shows that the development of the tertiary industry and the increase of urban population density can reduce household energy consumption to a certain extent. On the other hand, R&D and per capita GDP have a positive effect on household energy consumption, with elastic coefficients of 0.0595 and 0.0230 respectively. This shows that technological progress in energy conservation and emission reduction should not only be biased towards the energy consumption of industrial production, but also improve low-carbon intensive technologies in daily life.

And the model passed the AR test and Sargan test, indicating that the selection of instrumental variables is reasonable and the regression results of the model are trustworthy.

The Influence of Household Energy Consumption Habit Effect

From the model results, it can be seen that household energy consumption habits can significantly promote the level of household energy consumption, which is also consistent with previous studies [38, 39]. Urbanization increases household income by providing more employment opportunities and better public services (such as education), and urban households tend to have younger heads of households, smaller families, and smaller living areas [38, 39]. At the same time, urbanization has changed related infrastructure and equipment, such as residential characteristics and energy-consuming equipment. For example, urbanization has changed the residents' energy choices, increased the amount of heat insulation in their homes, and directly changed their energy consumption. All these differences in household characteristics affect their lifestyle and energy consumption behavior.

With the improvement of the level of urbanization and people's living standards, the urban consumer groups continue to expand and the consumption structure continues to upgrade. As a result, expenditures for consumption materials such as food, clothing, and use will decrease, and the proportion of enjoyment consumption such as housing, transportation, communication, culture and entertainment will increase, which will promote the continuous increase of urban residents' energy consumption. Therefore, the government adopts appropriate policies to guide consumer behavior when regulating the macro economy. This will not only ensure sustained economic growth, but also ensure the development of energy-saving consumption patterns for residents.

The government can also start with publicity and education to change residents' consumption habits. Compared with traditional media propaganda and preaching, scholars generally believe that targeted and specific information guidance can allow residents to more clearly grasp their energy consumption status, so as to understand the feasible ways to improve their behavior, which may inspire residents to change their behavior [40, 41]. Darby et al. [42] found through empirical research on energy-saving communities in the UK that social learning methods such as carrying out community activities and setting a model have a significant effect on changing residents' energy consumption behavior, but the cost of implementing these methods is usually high. Ouyang et al. [43] used Hangzhou residents as a sample and adopted a control group experiment to prove that targeted energy-saving education for residents can effectively improve electricity consumption behavior, and save 10% of average daily electricity consumption. Researchers suggest that managers should pay more attention to such methods in residents' energy-saving management, rather than blindly pursue high-tech methods. And the formation of values mainly comes from the life experience of individual youth and the socialization process of growth, strengthening low-carbon energy-saving education at the basic education stage, and cultivating positive environmental values from an early age are very important to stimulate endogenous low-carbon behavioral will.

The Influence of Urbanization Level on Domestic Energy Consumption

The impact of urbanization level on household energy consumption has a significant double threshold effect of per capita disposable income. The two threshold values of the model with per capita disposable income as the threshold variable are 14,717.61 yuan and 21,989.05 yuan respectively. The overall level of urbanization has an inhibitory effect on household energy consumption, but it shows an inverted U-shaped trend. When the per capita disposable income is less than 14,717.61 yuan, the influence coefficient is –0.0079. When the per capita disposable income crosses the first threshold value, the suppression effect weakens, and the influence coefficient increases to –0.0016. After that, the inhibitory effect was strengthened again, and the influence coefficient decreased to –0.0042. From Fig. 3, it is observed that the two thresholds correspond to the time in 2007 and 2011, and the corresponding urbanization rates of the population are about 52% and 57%.

The reason why urbanization has a restraining effect on household energy consumption may be because, on the one hand, in the process of urbanization, the per capita disposable income of residents will have an inhibitory effect on household energy consumption. During the process of urban expansion, as the income of residents increased, the rural population began to migrate to towns, thereby reducing the dependence on biomass energy. On the other hand, people's demand for a better quality of life has led to a growing demand for amenities that are neither resource-efficient nor environmentally friendly, such as winter heating and energy-consuming household appliances [44, 45]. It can be seen from Fig. 4 that between 2000 and 2007, coal

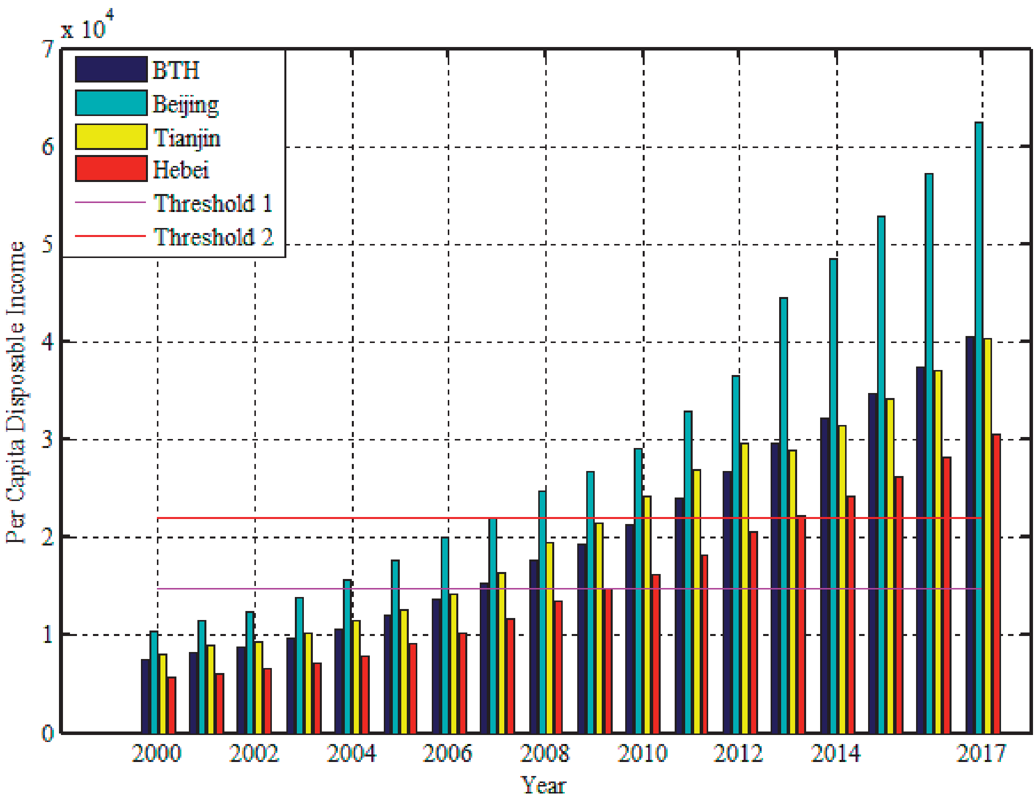

Fig. 3. Per Capita Disposable Income in Beijing, Tianjin, and Hebei.

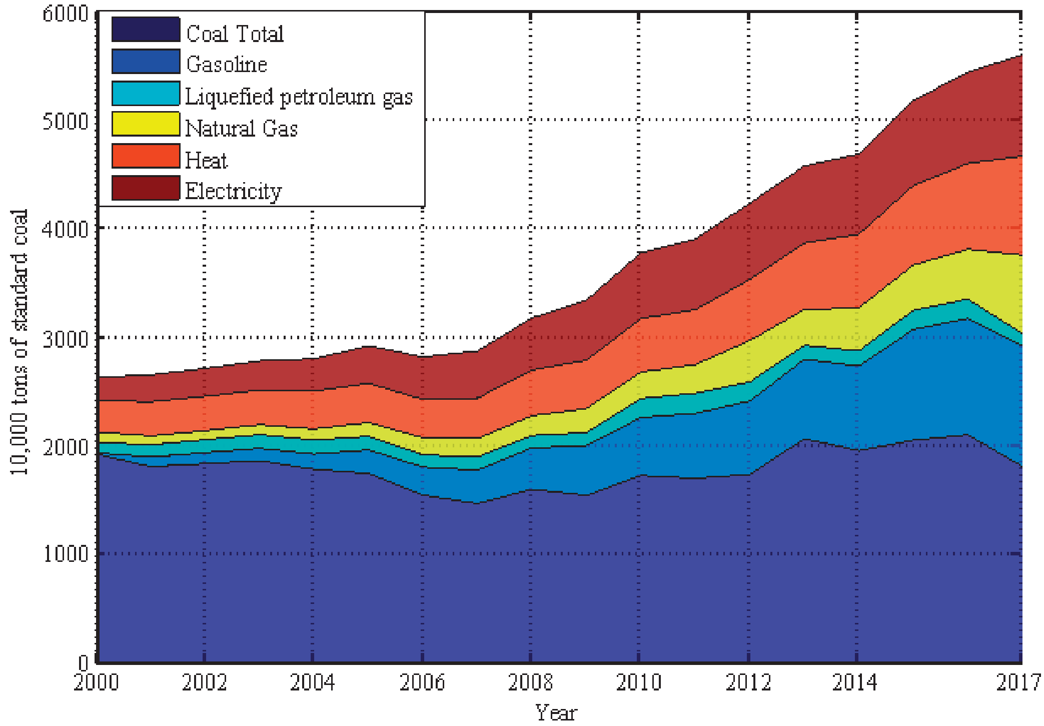

Fig. 4. Major energy consumption in BTH region.

decreased with increasing income, while oil, natural gas, and electricity increased with household income.

After the per capita disposable income crosses the first threshold, the urbanization rate begins to exceed 52%, and the inhibitory effect of urbanization on residential energy consumption weakens. This is because as residents' income rises, residents have further requirements for housing, transportation, and public facilities [44, 46]. Contradictions in urban construction and the concentration of urban diseases have erupted. The main manifestation is the blind expansion of urban planning and construction to the surrounding areas [44], occupation of a large amount of arable land, traffic congestion, and housing shortages, etc., which will lead to per capita household energy consumption of urban residents. There has been an increase, and coal consumption that had declined before 2007 also began to fluctuate slightly. At the same time, the use of gasoline, heat and electricity increased significantly, and the use of natural gas and liquefied petroleum gas also increased in different degrees. This is because natural gas has not been popularized in cities at this stage, and residents' lives are still mostly using electricity.

When the per capita disposable income crossed the second threshold of 21,989.05 yuan, the urbanization rate reached 57%. Compared with the previous stage, the inhibitory effect of urbanization on residential energy consumption in this stage has increased. As the process of urbanization continues to deepen, people's thinking about energy conservation and emission reduction has also been continuously enhanced, so that they will choose a more energy-efficient lifestyle. At this stage, oil and natural gas consumption has increased significantly. This is because, on the one hand, when the rural population is transformed into the urban population, as their incomes increase, their lifestyles, consumption patterns and consumption structure will shift to urban lifestyles. This shift has not only increased direct consumption of petroleum products, but also caused indirect demand due to people's consumption of other goods and services. In recent years, BTH regions have continuously promoted the use of new energy vehicles, from buses to private cars, from cities to towns, and this has eased oil consumption to a certain extent. On the other hand, with the increase in residents' income and the promotion of natural gas in cities, the consumption level of residents has risen, and the awareness of energy conservation has continued to increase. This has increased the consumption of natural gas and reduced the consumption of electricity, which to a certain extent is the reason why electricity consumption no longer increases significantly after 2012 (Fig. 4). Although coal consumption is still high, due to the restriction of natural resource endowments, the BTH region and even China will not be able to change the reality of coal-based energy for a long time in the future. Therefore, the main direction of coal consumption should increase the proportion of coal power generation and reduce the direct combustion of coal. Increasing the proportion of electric energy in the terminal energy and converting coal into electricity is an effective way to improve energy efficiency.

The Influence of Control Variables on Household Energy Consumption

In the dual threshold model with per capita disposable income as the threshold variable, for the control variables, industrial structure adjustment, urban population density, and residents' educational level have a restraining effect on energy consumption, and the elastic coefficients are -0.0746, -0.0040, and -0.2777. It can be seen that among the three, the education level of residents has the greatest restraint on household energy consumption, the adjustment of industrial structure ranks second, and the impact of urban population density is relatively small. This also shows that the government should pay more attention to the education level of residents and the adjustment of industrial structure. However, R&D and GDP per capita have a positive effect on household energy consumption, with elastic coefficients of 0.0595 and 0.0230 respectively. It shows that the government should be committed to the improvement of low-carbon intensive technology in the daily life of residents, not just energy saving and emission reduction in industry. The following specific analysis.

The Influence of Industrial Structure on Household Energy Consumption

The adjustment of industrial structure has a restraining effect on residents 'energy consumption, and the elasticity coefficient is –0.0746. It shows that the development of the tertiary industry under the effect of urbanization has a positive impact on reducing household energy consumption. This also coincides with the consumption trend of people's consumption tendency gradually changing from subsistence consumption to development and enjoyment consumption as the per capita disposable income increases year by year in the process of urbanization. Because the tertiary industry's dependence on energy is low, coupled with China's economic development in a "structural deceleration", the trend of tertiary industrialization has continued to highlight, promoting the reduction of energy consumption. Based on the original data and Fig. 5a) and b), it is found that the proportion of tertiary industry output value in BTH region rose from 43.55% in 2000 to 60.08% in 2017, and the proportion of tertiary industry output value in Beijing has already exceeded 70% in 2005-2006, reaching the level of cities in developed countries.

While Tianjin's pace is slightly behind, Hebei is at the bottom. From Fig. 5c) and d), it can be seen that the proportion of secondary industries in Tianjin and Hebei is still relatively large, so Tianjin and Hebei should control the high consumption in the industrial sector. The development of the energy industry, strictly control the entry barriers of high energy-consuming industries, curb the excessive growth of high energy-consuming industries at the source, and take measures to eliminate backward production capacity and resolve excess

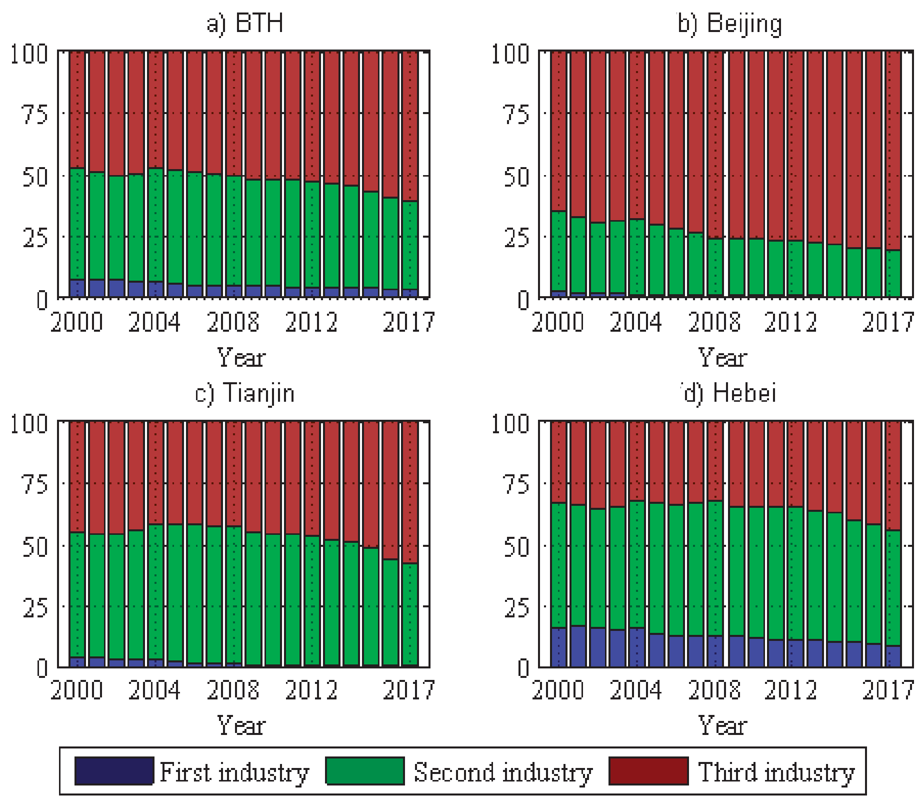

Fig. 5. Proportion of output value of primary, secondary and tertiary industries in a) BTH region, b) Beijing, c) Tianjin, and d) Hebei.

capacity to transform and upgrade such industries, so that it will develop in the direction of high-tech industries. On the basis of a certain level of economic development, the tertiary industry can be used as a long-term means of reducing energy consumption per unit of GDP [48]. Therefore, in the process of coordinated development in the BTH region, it is necessary to actively develop emerging industries and tertiary industries, optimize the industrial structure, promote new industrialization, strictly control the growth rate of industrial sectors with high energy consumption, and further accelerate the development of high-tech industries.

The Influence of Urban Population Density on Household Energy Consumption

Urban population density has a restraining effect on residents' energy consumption, and the elasticity coefficient is –0.0040. As a large number of people rush into cities from rural or remote areas, the density and energy efficiency of the population reduce the energy consumption of residents. There are three main reasons for this phenomenon. First, the increase in population density is generally accompanied by an increase in the number of households, thereby increasing the efficiency of household appliances and fuel gas. Second, the higher the population density, the smaller the per capita living area and the concentration of residential housing, which reduces the energy consumption due to the construction of housing. Third, the increase in population density has caused traffic congestion, and people have become more inclined to choose large-capacity public transport such as subways and buses, thereby reducing the energy consumption caused by private cars.

Although increasing urban density can shorten commuting distances and reduce people's dependence on private cars. It can also reduce energy transmission and distribution losses, and achieve the purpose of energy saving by realizing the scale effect of public facilities. However, in real life, the negative impact caused by high probability of traffic jams and exhaust emissions is often greater than the savings benefits brought by compact space. Therefore, in the process of urbanization, with the improvement of residents' income level, in order to reasonably control the total household energy consumption, spatial urbanization should be given priority on the basis of balancing population urbanization and spatial urbanization, so as to improve the quality and efficiency of urbanization [49].

The Impact of Technical Progress on Domestic Energy Consumption

R&D have a positive impact on the household energy consumption, with a coefficient of elasticity of 0.0595. This is consistent with the research conclusion of Yang et al. [50] The possible explanation for this is that on the one hand, China's technological progress in energy conservation and emission reduction is more inclined to energy consumption in industrial production, and low-carbon intensive technologies in daily life need to be improved. As far as the BTH region is concerned, the R&D expenditure of low-carbon energy-saving technologies in Tianjin and Hebei accounts for a relatively low proportion in the low-carbon economy. This also reflects from the side that there is still considerable potential for research and development of low-carbon energy-saving technologies in the BTH region. On the other hand, the expansion of urbanization has transformed a large number of rural residents into urban residents, and their lifestyles have also changed to urban lifestyles. Residents rely on the upgrading of the consumption structure of energy-intensive products. In the process of urbanization, they also need private and public facilities to meet the needs of the growing urban population and urban economy. The structural effect promotes the improvement of energy efficiency and thus reduces the consumption of household energy, but in fact the rebound effect of technological progress is not enough to offset the household energy consumption it promotes. In the end, it leads to an increase in residential energy consumption, which makes it still a stimulating effect on per capita household energy consumption in urbanization. At the same time, technological progress has promoted economic growth and increased incomes of residents indirectly increasing the tendency of residents' energy consumption.

The Impact of GDP Per Capita on Household Energy Consumption

The GDP per capita has a promoting effect on residents' energy consumption, and the elasticity coefficient is 0.0230, indicating that economic growth in the BTH region will promote energy consumption. Many studies suggest that China's economic growth and energy consumption are inseparable [51, 52]. From the perspective of economics, the relationship between energy consumption and economic growth is mainly as follows: First, economic growth depends on energy, which indicates that the former will be affected by the latter. Second, economic growth is the development condition for energy, so the significance of energy existence can only be reflected through economic growth.

Economic growth can promote energy development, but energy and environmental problems caused by energy consumption will gradually hinder economic development. The impact of energy on economic growth has received widespread attention from various countries because the level of energy satisfaction can determine the level of economic growth achieved. Energy has played an important role in promoting the development of the world economy and has a great influence on the growth rate of the economy. Economic growth depends on energy consumption, but it can also provide energy for energy development. In other words, while economic growth generates energy demand, it also provides a means to meet this demand, and the relationship between energy and economy will not disappear due to energy shortage.

The Influence of Human Capital on Household Energy Consumption

Under the constraints of urbanization, human capital has a significant curbing effect on energy consumption, with an elasticity coefficient of –0.2777. Urbanization not only gathers the population, it is more important to accumulate human capital and bring about a huge "human capital dividend". Under the constraints of urbanization, the overall quality of workers is improved, more convenient vocational technologies are obtained, and the optimal allocation of human capital is achieved. It is easier to accept advanced knowledge and technology, improve labor productivity, and reduce energy waste. At the same time, it also creates good conditions for technological progress. The integration and promotion of the two will jointly reduce energy consumption intensity and energy consumption. And the education level is positively related to environmental concerns, that is, the higher the education level, the higher the level of environmental concern, the higher the education level of the main members of the family, the more they prefer to use technology to save energy to improve energy efficiency and reduce energy consumption [53].

Conclusions

This paper uses the panel data of the BTH region from 2000 to 1017, and combines the threshold model with the GMM method to develop a dynamic threshold panel model, which helps to solve the endogenous problem between variables. Then, the per capita disposable income is selected as the threshold variable, and the dynamic threshold panel model is used to verify the nonlinear relationship between the urbanization process of the BTH area and the household energy consumption. The conclusions of the empirical analysis and some policy recommendations given in this article are as follows.

(1) There is an obvious threshold effect between urbanization and domestic energy consumption in the Beijing-Tianjin-Hebei region. The overall level of urbanization has an inhibitory effect on the energy consumption of residents, but it shows a significant inverted U-shaped development trend. When the per capita disposable income is less than 14717.61 yuan, the urbanization rate will increase by 1% and the energy consumption of residents will be reduced by 0.79%. When the per capita disposable income is greater than or equal to 14717.61 yuan and less than 21989.05 yuan, the urbanization rate will increase by 1% and the energy consumption of residents will be reduced by 0.16%. With the further development of the economy, when the per capita disposable income is greater than 21989.05 yuan, the urbanization rate will increase by 1%, and the residential energy consumption will decrease by 0.41%.

(2) The habit effect of life energy consumption can significantly promote the level of life energy consumption. That is to say, the one-phase lagging item of residential energy consumption can promote the residential energy consumption of this period.

(3) Industrial structure adjustment, urban population density and education level of residents have a restraining effect on energy consumption, while R&D and per capita GDP have a promoting effect on energy consumption.

Some policy recommendations:

(1) In the process of coordinated development of the Beijing-Tianjin-Hebei region, attention should be paid to Hebei Province, which has a relatively low per capita disposable income. It can be considered to alleviate the imbalance in energy consumption in life by increasing the disposable income of residents.

(2) In the process of urbanization, it is necessary to reasonably change the household energy consumption habits of residents, and increase the proportion of clean energy and high-efficiency energy in household energy. In addition to continuing to expand the proportion of natural gas and other clean energy consumption, the government can also use price leverage to regulate the energy consumption of urban and rural residents.

(3) Beijing should focus on the development of the tertiary industry that meets the functional requirements of the capital, and can export the development experience of the tertiary industry to Tianjin and Hebei Province. At the same time, the industrial industries in Tianjin and Hebei will be promoted towards high-tech industries.

(4) Adopt a more intensive urban planning development model. For very large cities with high population concentration, the strategy of structured evacuation and concentration can be adopted simultaneously to avoid diseconomies of scale caused by excessive population concentration. At the same time, the population concentration of small and medium cities can be appropriately increased, and total energy consumption can be reduced through facility sharing and energy structure optimization.

(5) Continue to focus on shaping people's awareness of energy conservation and emission reduction in higher education. Enhance people's sense of social responsibility, and then promote the realization of China's energy conservation and emission reduction goals nationwide.

(6) The government should also commit to the improvement of low-carbon intensive technologies in the daily lives of residents, not just the industrial energy saving and emission reduction.

(7) In the process of coordinated development of Beijing-Tianjin-Hebei, attention should be paid to the development of high-tech industries and

high-end service industries in Tianjin and Hebei. Promote its transfer from a resource-endowment type with high energy consumption to a resource-friendly industry with low energy consumption, and realize the decoupling of economic development and energy consumption.

There are still some shortcomings in this article: the use of data is short, and the results may be biased. It is only an overall analysis of the impact of the tertiary industry on the residents' total energy consumption in the process of urbanization, without a specific analysis of the changes in residents' energy consumption structure. It does not distinguish between the direct and indirect effects of urbanization on domestic energy consumption. Scholars can start new research from these aspects.

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