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RESEARCH ARTICLE

On the nonlinear relationship between energy consumption and economic and social development: evidence from Henan Province, China

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Abstract
The sustainable development of China's economy and society has been restricted by energy and environmental issues. With the implementation of the Rise of Central China strategy, Henan, a populous province in China, is facing the threat of an energy shortage as its economy grows steadily and the urbanization process accelerates. Using panel data of 18 cities in Henan Province for the period of 2006–2018, this study investigates the relationship between energy consumption and economic and social development variables based on the extended Stochastic Impacts by Regression on Population, Affluence, and Technology (STIRPAT) model and threshold regression method. The empirical results indicate that economic and social development are significantly positively correlated with total electricity consumption, although there is regional heterogeneity in this relationship. Moreover, there is evidence for a nonlinear relationship between economic and social development and urban energy consumption. These conclusions not only promote the healthy and sustainable economic development of Henan Province but also provide a reference for other provinces and cities that are experiencing rapid development in China.

Keywords Henan Province · STIRPAT model · Threshold regression · Nonlinear relationship

Introduction

On 17 June 2020, BP p.l.c. released the 69th edition of the BP Statistical Review of World Energy. The review shows that the world is embarking on a more sustainable road, but at the same time, energy shortages, rising energy prices, energy security, and other energy issues have become increasingly prominent, hindering the continuous development of countries (BP 2020). As a basic material for human survival and social production activities, energy resources have always been a vital support for economic and social development (Kabir et al. 2018; Wu et al. 2020). How to correctly understand and handle the relationship between energy and economic and social development has been an important topic in energy economics research (Aqeel and Butt 2001; Azlina and Mustapha 2012; Hong et al. 2019).

In the past 40 years, since Kraft J. and Kraft A. pioneered the analysis of the relationship between energy consumption and economic growth in the USA in 1978, scholars from various countries have done much empirical work in this field (Glasure and Lee 1998; Asafu-Adjaye 2000; Belke et al. 2011). Early studies focused on the relationship between energy consumption and GDP. For example, Soytas and Sari (2003) studied the causal relationship between energy consumption and GDP in 16 countries. The results revealed that in Turkey, France, Germany, and Japan, the relationship between energy consumption and GDP was that energy consumption promoted economic growth, while in Italy and South Korea, the causal relationship was the opposite, and in Argentina, a two-way causal relationship was manifested. Subsequently, scholars gradually added a series of other economic variables to the empirical study and found that energy consumption may also have an impact on financial development, capital, import and export, and international trade (Shahbaz et al. 2013). Furthermore, Bakirtas and Akpolat

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(2018) found that there is an inseparable relationship between energy consumption and urbanization in emerging market countries, indicating that energy consumption may also influence social development. In general, due to differences in data and region selection, the conclusions reached by scholars are not uniform.

As one of the fastest-growing economies in the world, China accounts for more than three-quarters of the net increase in global energy consumption (BP 2020), and its demand for energy has shifted from export to import (Wei et al. 2019). This fully indicates that with the development of the economy, China's energy supply has been unable to meet the needs of economic growth, so the effective use of energy has become an urgent problem. China is a typical country with more coal and less oil. Oil and gas resources are mostly dependent on imports, which makes China's energy consumption structure relatively unbalanced. Among them, according to the National Bureau of Statistics, in 2019, China's industrial coal production above designated size was 3.75 billion tons, an increase of 4.2% over the previous year, while total energy consumption increased by 3.3% over the previous year. Among them, the proportion of natural gas, hydropower, nuclear power, wind power, and other clean energy consumption in total energy consumption increased by 1.0% over the previous year, and the share of coal consumption dropped by 1.3%. This is the result of China's energy consumption reform. Therefore, the significance of this reform and the impact on environmental pollution and economic growth are all worth exploring. This paper selects the data of 18 cities[1] in Henan Province from 2006 to 2018 to conduct an empirical analysis not only because Henan is a large province in terms of population and consumption in China (Gao 2011) but also because with the implementation of the Rise of Central China strategy, stable economic growth and accelerated urbanization have made Henan's energy consumption exceed energy production. In this context, this paper is based on an extended STIRPAT model and threshold regression method to clarify the relationship between economic growth and energy consumption. The empirical results indicate that the economic and social development of Henan Province is significantly positively correlated with total electricity consumption, although there is regional heterogeneity. Moreover, there is a nonlinear relationship between economic and social development and urban energy consumption. These findings are not only conducive to promoting the healthy and sustainable economic development of Henan Province but also provide a reference for the energy strategy of other provinces and cities in China.

The main contributions of this study are threefold. First, previous papers mostly studied the causal relationship between two variables, such as economic growth and energy consumption (Han et al. 2004; Akinlo 2008; Han and Wu 2018), while this paper explores the relationship between energy consumption, economic growth, urbanization and technology spillover in a comprehensive framework, which helps improve our understanding of the internal mechanism of the environmental regulation emission reduction effect. Second, this paper uses threshold regression to test the possible nonlinear relationship to more realistically reveal the relationship between energy consumption and economic and social development variables. Third, this paper analyzes the regional heterogeneity of different cities in Henan to describe regional differences more accurately and put forward contrapuntal policy suggestions.

The rest of this paper is organized as follows. "Literature review" presents the literature review. "Methodology and data" features the estimation methodology and the data utilized in this study. "Empirical results analysis" presents the empirical results. "Discussion" contains the discussion on the estimation results, while "Policies and recommendations" provides the conclusions and related policy implications.

Literature review

After adequately considering the factors that may affect energy consumption, in this section, we will focus on four aspects: economic growth and energy consumption, industrial structure and energy consumption, international technology spillover and energy consumption, and urbanization and energy consumption in a review of the previous literature.

Economic growth and energy consumption

As early as more than 40 years ago, the relationship between energy consumption and economic growth attracted the attention of scholars (Kraft and Kraft 1978) and then became a hot topic in energy economics (Aqeel and Butt 2001; Soytas and Sari 2003; Azlina and Mustapha 2012; Yi 2015). On the one hand, economic growth needs energy as material support, so economic growth is often accompanied by increased energy consumption (Hossain 2011; Begum et al. 2015; Kabir et al. 2018). Hossain (2011) selected time series data from 1971 to 2007 and confirmed that there is a one-way short-term causal relationship between economic growth and energy consumption in emerging countries. By exploring the relationship between economic growth and energy consumption in Malaysia using multiple methods, Begum et al. (2015) also found that with the increase in per capita

[1] Cities in China can be divided into prefecture-level city and provincial city according to administrative levels. The former is a city with traditional concepts in terms of population, urban area, and economic scale, while the latter is not as good as the population size and urban area of normal cities, but due to their important status, are cities directly under the jurisdiction of the provincial government. Seventeen prefecture-level cities (i.e., Zhengzhou, Kaifeng, Luoyang, Pingdingshan, Anyang, Hebi, Xinxiang, Jiaozuo, Puyang, Xuchang, Luohe, Sanmenxia, Nanyang, Shangqiu, Xinyang, Zhoukou, and Zhumadian) and a provincial city (Jiyuan) were included.

GDP, energy consumption gradually increased, and per capita carbon dioxide emissions also increased sharply. Rahman and Velayutham (2020), based on a study of five South Asian countries from 1990 to 2014, revealed that both renewable and nonrenewable energy consumption have a positive impact on economic growth. In return for unreasonable energy use, economic growth will destroy the ecological environment and eventually lead to a high cost of development (Sadakata 2003; Wang et al. 2018; Wu et al. 2020). In China, for example, due to the excessive pursuit of high-speed economic growth in the early stage of development, unreasonable energy utilization caused a large increase in harmful gas emissions, leading to severe air pollution that gradually threatened people's physical and mental health (Gu et al. 2012; Liu et al. 2017; Zhang et al. 2017). In addition, the emissions of various solid and liquid pollutants increased far beyond the self-purification capacity of the environment, aggravating land and water pollution (Lu et al. 2015; Wang and Yang 2016), all of which hindered the healthy and sustainable development of the economy and society. In contrast, high-quality economic growth may advance the energy utilization technology level and perfect the energy utilization policy system (Wüstenhagen and Bilharz 2006) to optimize the energy consumption structure and improve energy consumption efficiency.

Industrial structure and energy consumption

Industrial structure is also commonly considered one of the main factors affecting energy consumption (Sinton and Levine 1994; Hong et al. 2019). Gagnon et al. (2002) studied past and future trends of energy supply and demand in Japan. The results showed that the growth trend of Japan's energy demand tended to be stable, mainly owing to the transformation of the industrial structure from raw materials and heavy industry to service industry. Generally, the secondary industry is regarded as a high-energy-consumption industry, while the tertiary industry, namely, the service industry, is often regarded as a low-energy-consumption sector. Therefore, the higher the proportion of the secondary industry in the national economy or the lower the proportion of the tertiary industry, the higher the energy consumption is (Yuan et al. 2014; Hao and Peng 2017). Deng et al. (2014) and Mi et al. (2015) used data from all of China and certain provinces in China, respectively, and their research results indicated that through reasonable industrial structural adjustment, energy intensity could be reduced without affecting economic growth. Kurniawan and Managi (2018) carried out an empirical analysis on the factors that may affect energy consumption in Indonesia and found that a decrease in the proportion of the secondary industry reduced coal consumption. In addition, many scholars have focused on the study of the energy consumption influencing factors of specific industries. For example, Arens et al. (2012) found that the steel industry was the largest industrial CO_2 emitter and energy consumer in the world and analyzed the development of the energy efficiency of the steel industry in Germany over 16 years, and Martínez (2010) compared the energy use and energy efficiency of the textile industry in Germany and Colombia in the sample period.

International technology spillover and energy consumption

Many studies have suggested that the improvement of the technology level is conducive to enhancing energy utilization efficiency and reducing energy consumption (Begum et al. 2015). For example, Martínez (2010) found that in textile manufacturing activities in Colombia, the promotion of energy efficiency was achieved mainly through R&D investment in the production process and application of new technologies. With the acceleration of the process of global integration, trade ties between countries have become increasingly close. In this process, advanced technology owners in multinational corporations transfer or disseminate their technology consciously or unconsciously through FDI, namely, technology spillover. Paramati et al. (2016) estimated the short-term and long-term relationship between FDI and clean energy consumption. The results show that the spillover of FDI has a significant positive impact on clean energy consumption, suggesting that policy makers ought to provide profitable incentives to attract foreign clean energy technology inflow or cooperation. Dong et al. (2019) pointed out through empirical research that FDI does not have an income inequality effect; that is, there is no evidence that FDI flowing into low-income areas increases energy consumption, while FDI flowing into high-income areas can save energy. At the same time, the relationship between trade openness and energy consumption has also begun to attract the attention of researchers. Studies on Thailand (Kyophilavong et al. 2015), Turkey (Cetin et al. 2018), and the BRICS countries (Sebri and Ben-Salha 2014) all showed that there is an inseparable link between energy consumption, economic growth, and trade openness.

Urbanization and energy consumption

The existing empirical research indicates that the impact of urbanization on energy consumption is realized in two ways. First, the process of urbanization is often accompanied by the expansion of industrialization. Due to the mass of infrastructure construction and the use of transportation tools, urbanization will become an important factor affecting energy consumption and climate change. A study on Tunisia pointed out that there is a long-term relationship between industrialization and urbanization, and a long-term bidirectional causal relationship was found between industrialization and energy consumption (Shahbaz and Lean 2012). In a study on coal energy consumption in Indonesia, Kurniawan and Managi (2018) also discovered that urbanization multiplied coal consumption. Second, the agglomeration effect of urbanization improves the efficiency of energy utilization, thus reducing energy consumption. Liu et al. (2018) analyzed the carbon emission efficiency of 10 typical urban agglomerations in China from 2008 to 2015. The results of the ideal point crossing efficiency (IPCE) model show that the population effect and economic effect would improve the carbon emission efficiency of mature urban agglomeration. Some studies have pointed out that different patterns of urbanization will lead to different impacts on energy consumption. Therefore, there is no unified conclusion on the relationship between urbanization and energy consumption. Li and Lin (2015) divided 73 countries into four groups according to the annual income level from 1971 to 2010. The results showed that in the low-income group, urbanization reduced energy consumption, while in the middle-income and high-income groups, strong evidence to the contrary was uncovered, opening up a broader space for the study of the relationship between urbanization and energy consumption.

In summary, although scholars have discussed the relationship between energy consumption and economic and social development variables, the results display plenty of variation due to different research objects and sample periods. In addition, there are still some deficiencies in the existing research. For instance, in the experimental design, most of them have focused on the linear analysis or causal analysis of energy consumption and economic and social development variables but neglected to consider a possible nonlinear relationship; in the selection of variables, they have covered few economic and social development variables; and in the empirical analysis, they have insufficiently considered regional heterogeneity.

Methodology and data

The derivation of the basic model

In 1971, Ehrlich and Holdren creatively used the $I = PAT$ formula to describe the impact of population growth on the environment. The main idea is that the total environmental impact (I) is a multiplier function of population size (P), affluence (A), and environmental damage caused by consumption and production technology (T) (Ehrlich and Holdren 1971). Since then, scholars have begun to modify and optimize the model (Dietz and Rosa 1994; Hansen 1999; Schulze 2002; Nakicenovic 2004; Xu et al. 2005). In 1994, Dietz and Rosa (1994) redefined IPAT as a stochastic model called STIRPAT (Stochastic Impacts by Regression on Population, Affluence, and Technology) that can statistically simulate the nonproportional effects of variables on the environment. The standard STIRPAT model is as follows:

$$I_i = aP_i^b A_i^c T_i^d e_i \tag{1}$$

Equation (1) is based on the multiplication logic of the $I = PAT$ equation and still includes only P, A, and T as the influencing factors of I. After taking logarithm, the model represented by Eq. (1) becomes:

$$\ln I_{it} = a + b(\ln P_{it}) + c(\ln A_{it}) + d(\ln T_{it}) + e_i \tag{2}$$

where the subscript i represents the observed individual; t represents the observation period; a is a constant; b, c, and d are the coefficients of P, A, and T, respectively; and e is the residual term.

Later, York et al. (2003) pointed out that sociological or other controlling factors can be added to Eq. (2) as long as these additional factors are conceptually consistent with the multiplication norms of the model. Therefore, by adding the proportion of the added value of the tertiary industry in GDP (pth), urbanization rate (urb), R&D investment in GDP (rd), and financial expenditure in GDP (fin) into the control variables, this paper modifies Eq. (2) and obtains Eq. (3):

$$\begin{aligned}\ln I_{it} = {} & a + \beta_1(\ln P_{it}) + \beta_2(\ln A_{it}) + \beta_3(\ln T_{it}) \\ & + \beta_4(\ln pth_{it}) + \beta_5(\ln urb_{it}) + \beta_6(\ln rd_{it}) \\ & + \beta_7(\ln fin_{it}) + e_i \end{aligned} \tag{3}$$

The meanings and units of each variable are summarized in Table 1.

Threshold regression model

In recent years, some scholars have begun to pay attention to the nonlinear relationship between energy consumption growth and economic growth (Huang et al. 2008; Heidari et al. 2015). Therefore, to further investigate the possible nonlinear relationship, this paper uses Hansen's nondynamic threshold regression model for reference. First, we assume that there is a "single threshold effect" and introduce the logarithmic form of per capita GDP (A) into the model as a threshold variable. Based on Eq. (3), a piecewise function of the impact of energy consumption intensity (T) on electricity consumption (I) of the whole society is constructed, which is depicted in Eq. (4). We then test the threshold effect, estimate the threshold value, and finally estimate the coefficients in Eq. (4) by stepwise regression.

Table 1 Variable selection

Variables	Proxy variables	Variable symbol	Logarithmic form	Units
Energy consumption	Total electricity consumption	tel	ln tel	Hundred million kwh
Economic development	Per capita GDP	pgdp	ln pgdp	Yuan (based on 2000)
Population size	Total population	pop	ln pop	10,000 people
Technology	Power consumption intensity	power	ln power	KWh/10,000 yuan
Industrial structure	Proportion of added value of tertiary industry in GDP	pth	ln pth	–
Urbanization	Urbanization rate	urb	ln urb	%
R&D intensity	Proportion of R&D investment in GDP	rd	ln rd	–
Financial expenditure	Proportion of fiscal expenditure in GDP	fin	ln fin	–

$$\begin{aligned}\ln I_{it} = a + \beta_1(\ln P_{it}) + \beta_2(\ln A_{it}) + \beta_{31}(\ln T_{1it}) \\ \cdot I(A < \eta) + \beta_{32}(\ln T_{2it}) \cdot I(A > \eta) \\ + \beta_4(\ln pth_{it}) + \beta_5(\ln urb_{it}) + \beta_6(\ln rd_{it}) \\ + \beta_7(\ln fin_{it}) + e_i \end{aligned} \quad (4)$$

where A, i.e., per capita GDP is the threshold variable; η is the threshold value to be estimated, indicating different levels of economic development; and $I(\cdot)$ is the indicator function. If there is a multithreshold effect, the corresponding model can be extended from a single threshold model.

Threshold regression model

According to the extended STIRPAT model shown in Eq. (3), this paper selects the following variables for empirical study.

Explained variables

Energy consumption According to the data disclosed by Henan Electric Power Company of State Grid, the maximum power load of Henan Province Grid in 2019 is 64.89 million kwh and the total social power consumption is 336.417 billion kwh. Although the West-East Electricity Transmission Project has made up for the power shortage in Henan Province to a certain extent, the power supply and demand in Henan Province still present a "tight balance" (Gao and Ma 2008). Therefore, this study selects the whole society's electricity consumption as the explained variable for the sake of understanding the reasons for power consumption and finding solutions to the problem of power shortage in Henan Province.

The energy consumption of Henan Province in 2006 and 2018 is shown in Fig. 1 and Fig. 2, respectively.

Core explanatory variables

Population In light of the previous introduction of the STIRPAT model, this paper uses the total population as one of the core explanatory variables. Existing studies have often found that population has a positive correlation with environmental impact I (Lin et al. 2009; Liddle 2015). Some scholars have even claimed that population size has become a main persistent factor affecting the environment in all regions (Rosa et al. 2004).

The population of Henan Province in 2006 and 2018 is shown in Fig. 3 and Fig. 4, respectively.

Economic development This paper selects per capita GDP to describe the wealth degree described by per capita consumption or production, which basically conforms to the definition of A in the STIRPAT model (York et al. 2003). With the purpose of eliminating the impact of price changes, this paper takes 2000 as the base period to reduce the per capita GDP.

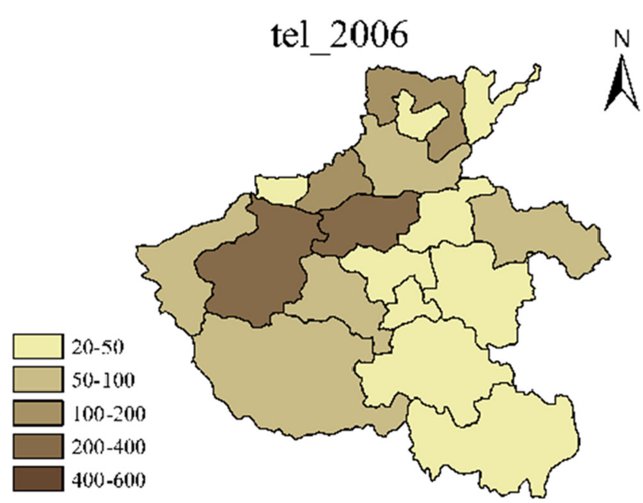

Fig. 1 Energy consumption of Henan Province in 2006

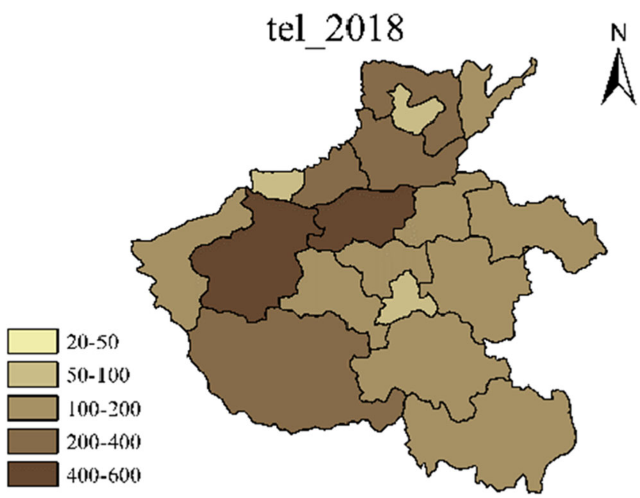

Fig. 2 Energy consumption of Henan Province in 2018

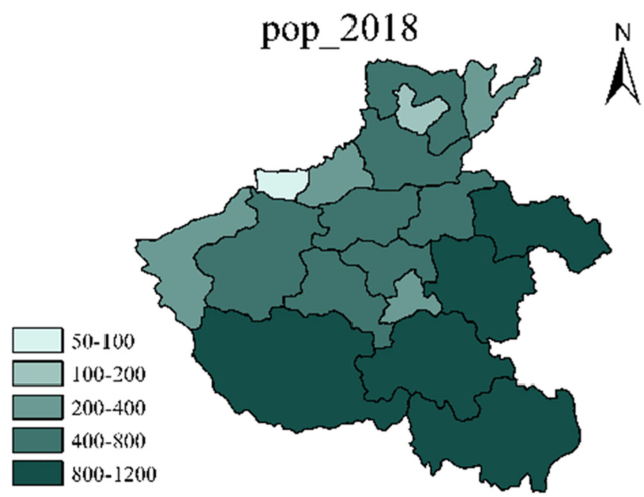

Fig. 4 Population of Henan Province in 2018

The economic development of Henan Province in 2006 and 2018 is shown in Fig. 5 and Fig. 6, respectively.

Technology In this study, the technical indicators are measured by the power consumption intensity and calculated by the total electricity consumption/real GDP (based on the year 2000). A higher technical level can improve energy utilization efficiency and provide valid measures to diminish energy intensity (Lin et al. 2009).

The technology level of Henan Province in 2006 and 2018 is shown in Fig. 7 and Fig. 8, respectively.

Control variables

Industrial structure A search of the previous literature reveals that the industrial structure is also considered one of the factors affecting energy consumption (Deng et al. 2014; Mi et al. 2015; Hong et al. 2019). Therefore, this paper selects the proportion of the added value of the tertiary industry in GDP as the control variable to test the impact of industrial structure on energy consumption. This variable is derived from the added value of the tertiary industry/nominal GDP.

The industrial structure of Henan Province in 2006 and 2018 is shown in Fig. 9 and Fig. 10, respectively.

Urbanization This paper also includes the urbanization rate as one of the control variables. Since urbanization is often accompanied by the expansion of industrialization and urban agglomeration, it tends to have an influence on energy consumption (Shahbaz and Lean 2012; Kurniawan and Managi 2018).

The urbanization of Henan Province in 2006 and 2018 is shown in Fig. 11 and Fig. 12, respectively.

R&D intensity This variable is calculated by R&D investment/nominal GDP. By and large, the more funds spent on technology, the more beneficial it is to adopt environmentally friendly energy utilization technology, thus reducing the overall

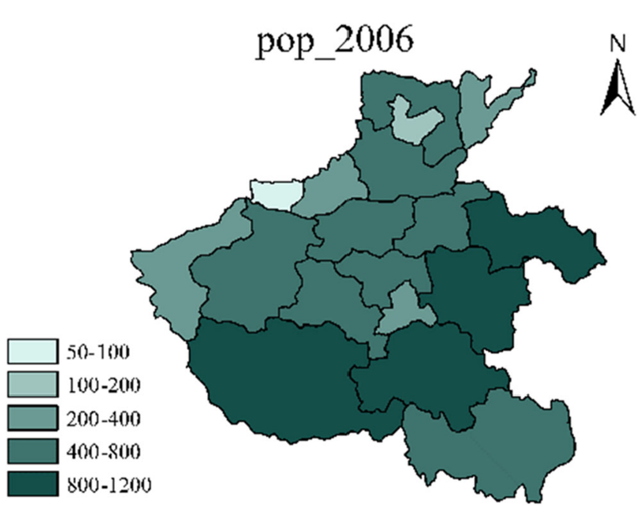

Fig. 3 Population of Henan Province in 2006

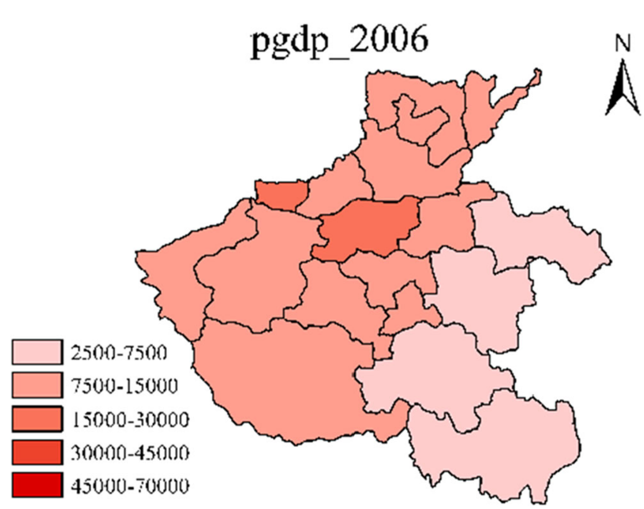

Fig. 5 Economic development of Henan Province in 2006

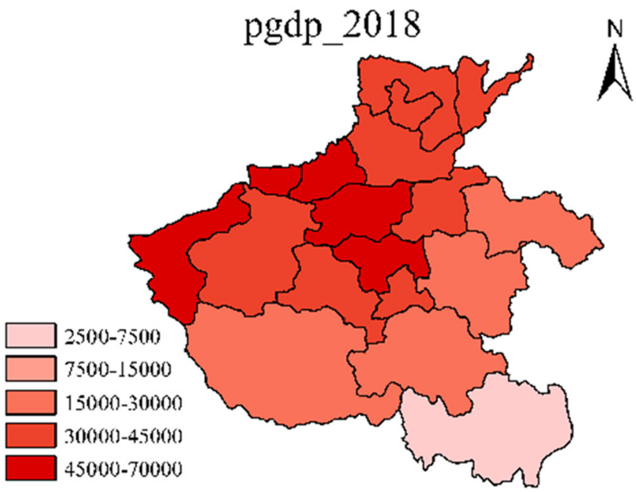

Fig. 6 Economic development of Henan Province in 2018

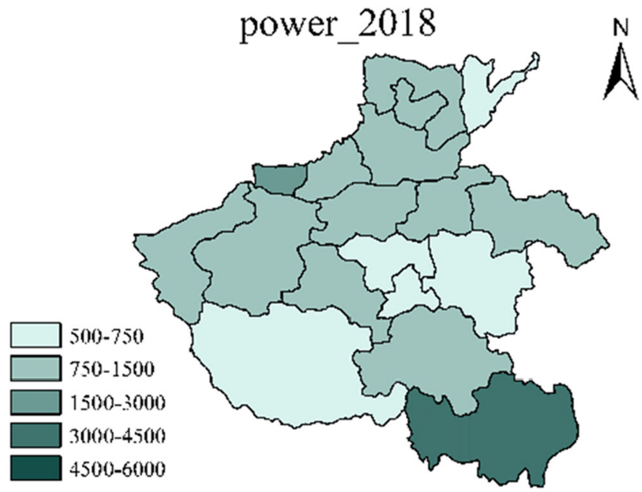

Fig. 8 Technology level of Henan Province in 2018

energy consumption and pollution emissions of society (Wang et al. 2017; Koçak and Ulucak 2019).

The R&D intensity of Henan Province in 2006 and 2018 is shown in Fig. 13 and Fig. 14, respectively.

Financial expenditure Since financial expenditure may affect the power consumption of the whole society in the form of energy subsidies, energy taxes, or construction of energy supply facilities (Liu and Li 2011), in this paper, the proportion of fiscal expenditure in GDP is added to the model as a control variable, and the corresponding value is obtained by means of financial expenditure/GDP.

The financial expenditure of Henan Province in 2006 and 2018 is shown in Fig. 15 and Fig. 16, respectively.

Descriptive statistics

Based on the panel data of 18 cities in Henan Province from 2006 to 2018, this paper studies the relationship between economic and social development factors and energy consumption in Henan Province. The data of total electricity consumption, total population, GDP, GDP index, urbanization rate, R&D investment, and financial expenditure from 2006 to 2018 are all extracted from the Henan Statistical Yearbook; the added value of tertiary industry comes from the China Statistical Yearbook Database (CSYD). Descriptive statistics of all variables are shown in Table 2.

Empirical results analysis

Benchmark regression results

This paper extends the traditional STIRPAT model and conducts an empirical analysis based on the extended model. The regression results are shown in Table 3. To ensure the robustness of the regression results, the model is analyzed by mixed regression, fixed-effect regression, and random-effect

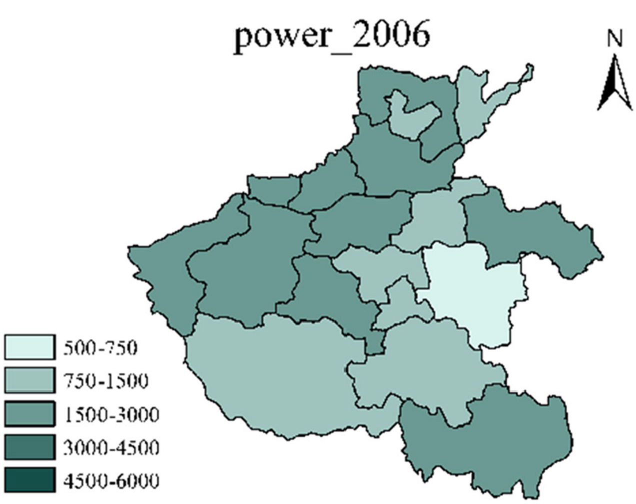

Fig. 7 Technology level of Henan Province in 2006

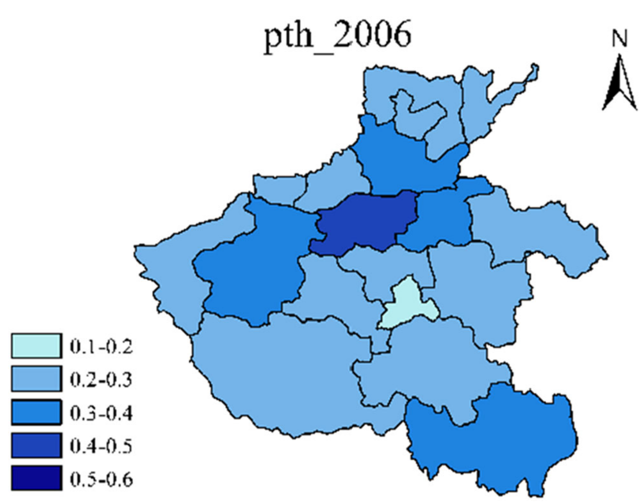

Fig. 9 Industrial structure of Henan Province in 2006

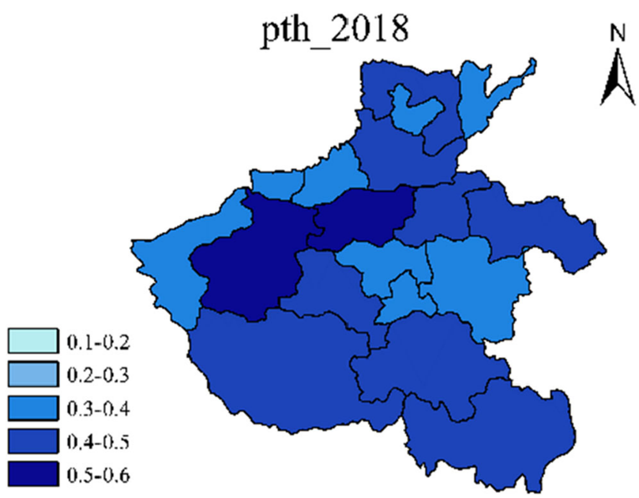

Fig. 10 Industrial structure of Henan Province in 2018

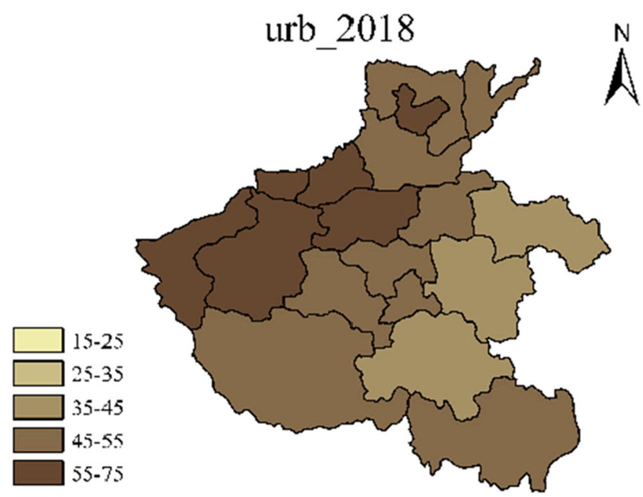

Fig. 12 Urbanization of Henan Province in 2018

regression. The results are listed in the first to third columns of Table 3. By comparison, we find that three main explanatory variables, economic development level, population size, and technological level, are affirmatively related to the total electricity consumption, which is consistent with economic theory. Furthermore, for the selection method of the panel data model form, we often use the *F* test to decide whether to choose the mixed regression model or the fixed-effect model. Through the *F* test, we find that the p value is zero, so the fixed-effect model is better than the mixed regression model. Therefore, this study chooses fixed-effect regression or random-effect regression. According to the Hausman test, we find that the value of *P* is zero, rejecting the null hypothesis that the random error term is not related to the explanatory variable. Therefore, the final regression result should be based on the fixed-effects regression result.

Through the analysis of the results of fixed-effect regression, we find that the main explanatory variables are obviously actively correlated with the whole society's electricity consumption, and the coefficients are less than 1, which does not violate economic theory. Among the three explanatory variables of the traditional STIRPAT model, the economic development level of Henan Province has the largest elasticity to electricity consumption; that is, every 1% increase in the economic development level extends the total electricity consumption by 0.990%, while the elasticity of the population size and technical level to the total society electricity consumption is 0.175 and 0.899, respectively. Among the control variables, the urbanization level has the greatest impact on the total electricity consumption in Henan Province. For every 1% increase in the urbanization level, the overall electricity consumption decreases by 0.183%. The second variable is the impact of financial expenditure on the total electricity consumption in Henan Province; for each financial expenditure increase of 1%, the total society electricity consumption increases by 0.076%. The influence coefficient of industrial structure on total electricity

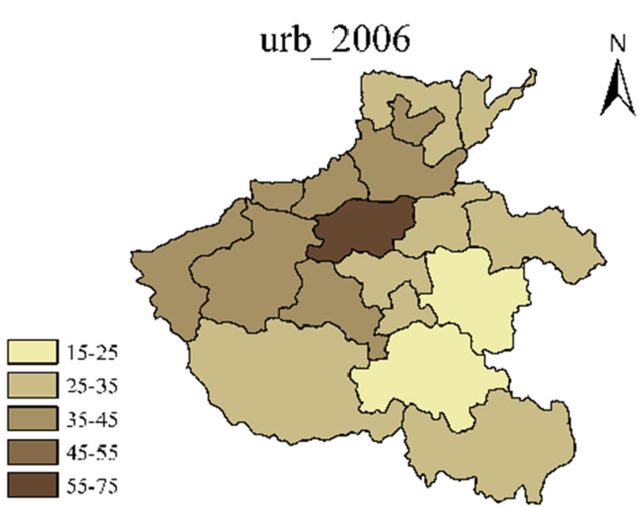

Fig. 11 Urbanization of Henan Province in 2006

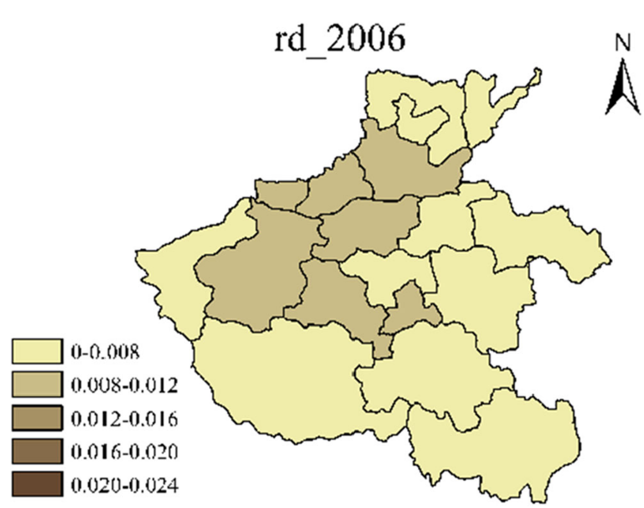

Fig. 13 R&D intensity of Henan Province in 2006

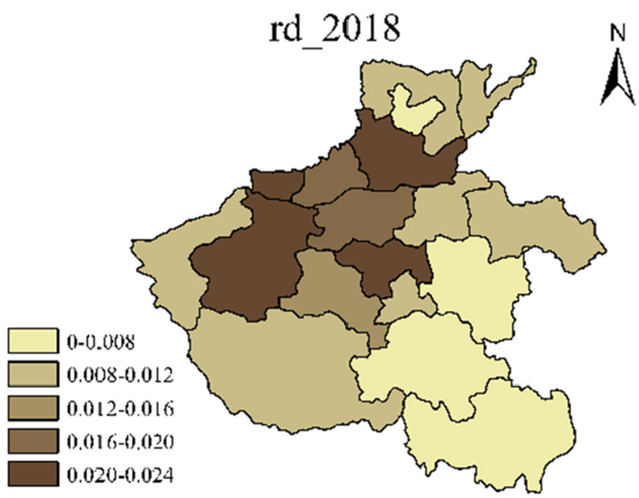

Fig. 14 R&D intensity of Henan Province in 2018

consumption is positive, while that of R&D intensity is negative. Additionally, the two influence coefficients are small and not significant.

Threshold regression results

To guarantee the significance and credibility of the threshold regression results, this paper first conducts the threshold effect test to explore whether there is a threshold effect, as shown in Table 4. According to Table 4, the test results reject the null hypothesis of no threshold effect, so it is reasonable to select the economic development level as the threshold variable, and there is only a single threshold effect.

In the process of threshold regression, this study adopts the method of stepwise regression; that is, the explanatory variables are added to the model one by one, and a t test is carried out to solve the problem of multicollinearity among the variables. The empirical results are shown in Table 5. The results show that the threshold value of the economic development level of Henan Province is 8.2547 when the logarithmic form of per capita GDP is the threshold variable. Table 5 shows the following findings:

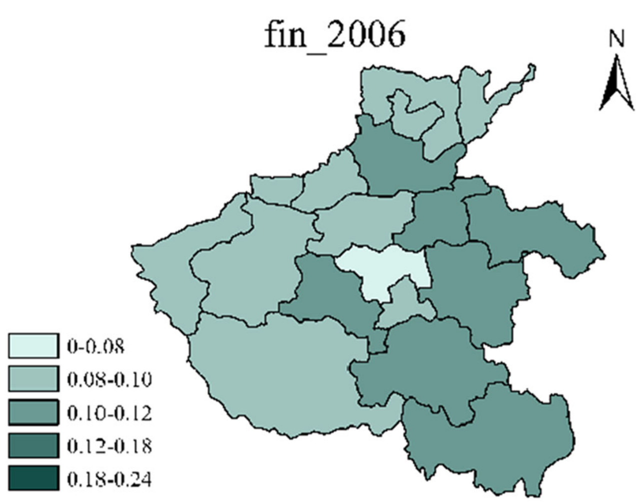

Fig. 15 Financial expenditure of Henan Province in 2006

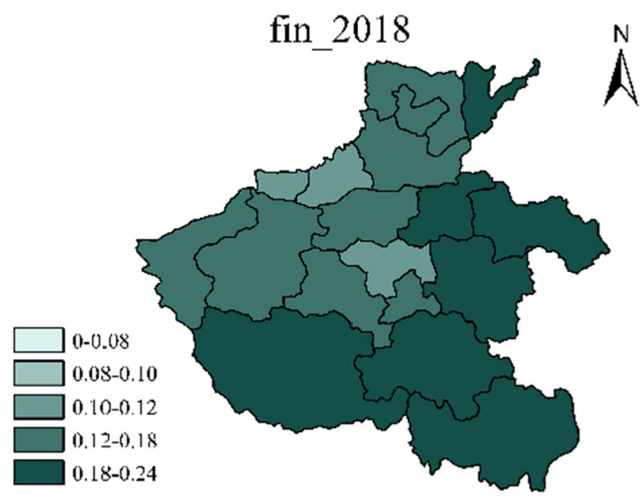

Fig. 16 Financial expenditure of Henan Province in 2018

1. Whether the economic development level of Henan Province is higher or lower than the threshold value, there is a significant affirmative correlation between the intensity of energy consumption and the total society electricity consumption, which means that the enhancement of energy consumption intensity will significantly accelerate the overall electricity consumption.
2. However, the statistical relationship between the intensity of energy consumption and the total electricity consumption is different above and below the threshold value. When the economic development level of Henan Province is below the threshold value, the total electricity consumption increases by 0.893% for every 1% increase in the energy consumption intensity, and when the level of economic development is above the threshold, the intensity of energy consumption increases by 1%, with the total electricity consumption increasing by 0.898%. Thus, the positive connection is relatively strengthened.

Table 2 Descriptive statistics

Variables	*N*	Mean	SD	Min	Max
lntel	234	4.712	0.692	3.187	6.329
lnpgdp	234	9.892	0.634	8.171	11.09
lnpop	234	6.161	0.705	4.209	7.088
lnpower	234	7.123	0.466	6.338	8.347
lnpth	234	−1.197	0.252	−1.758	−0.604
lnurb	234	3.760	0.222	3.027	4.296
lnrd	234	−4.978	0.838	−8.227	−3.844
lnfin	234	−2.021	0.270	−2.712	−1.464

Table 3 Regression results of the STIRPAT model

	OLS	FE	RE
lnpgdp	1.001***	0.990***	1.004***
	[0.026]	[0.022]	[0.026]
lnpop	1.015***	0.175***	0.894***
	[0.021]	[0.056]	[0.022]
lnpower	1.012***	0.899***	0.955***
	[0.025]	[0.019]	[0.023]
lnpth	−0.059	0.015	0.021
	[0.055]	[0.021]	[0.029]
lnurb	0.251***	−0.183***	−0.135**
	[0.077]	[0.051]	[0.067]
lnrd	−0.019	−0.002	−0.003
	[0.013]	[0.006]	[0.009]
lnfin	−0.226***	0.076***	−0.093***
	[0.035]	[0.025]	[0.028]
_cons	−20.212***	−11.708***	−17.197***
	[0.615]	[0.442]	[0.420]
F test		Prob > chi2 = 0.000	
Hausman		Prob > chi2 = 0.000	
N	234	234	234
R^2	0.992	0.990	0.980

Note: *t* value is in parentheses

***1%, **5%, and *10%—levels of significance

3. Regarding the other control variables, the parameter estimation of urbanization level is significantly negative, while financial expenditure is apparently active, and the parameter estimations of industrial structure and R&D intensity are not evident, which is consistent with the results of benchmark regression, showing the robustness of the results. Through threshold regression analysis, this paper further explores the nonlinear relationship between economic development, energy consumption intensity, and electricity consumption in Henan Province.

Heterogeneity test

Henan is a large province in the Central Plain, with 17 prefecture-level cities under its jurisdiction and one county-level city under its direct control. It has a total population of 109.52 million and a total area of 167,000 km^2. The climate and geographic conditions are complex, and it is in the central zone of westward echelon development, which has led to unbalanced economic development. Therefore, the analysis of the relationship between economic and social development and energy consumption at the level of Henan Province alone will ignore divergences between cities at disparate levels of economic development. Therefore, this section analyzes the heterogeneity of 18 cities in Henan Province according to economic development level, population size and energy consumption intensity. The results are shown in Tables 6, 7, 8. The classification method ranks 18 cities from high to low according to the survey index and divides them equally into high, middle and low groups.

As Table 6 shows, the divergences between cities at diverse levels of economic development are obvious. For example, the expansion of population size in cities at a low level of economic development leads to a decrease in electricity consumption; however, the increase of population size in medium-level and high-level cities has resulted in higher electricity consumption. Meanwhile, divergence is also manifested in the industrial structure; in low-level cities, the industrial structure has a positive effect on the total electricity consumption. As the level of increasing economic development, this effect becomes negative. In addition, the greater the level of economic development, the stronger the positive effect of per capita GDP on electricity consumption is, and the stronger the negative effect of urbanization on total electricity consumption.

When the population size is taken as a criterion, the results are dissimilar, as shown in Table 7. With the expansion of population size, the contribution of energy intensity to the total electricity consumption is weakened, while the relationship between population size and R&D intensity on the total electricity consumption changes from positive to negative. In small or medium-sized cities, an increase in population leads to an increase in the social consumption of electricity. In cities with sizable populations, the opposite is true. Moreover, urbanization level has no palpable effect on electricity consumption.

When energy consumption intensity is used as the standard, there is another change in the relationship between economic and social development and energy consumption, as shown in Table 8. A city with greater energy consumption intensity has a stronger role in promoting total electricity

Table 4 Threshold effect test

	Threshold value	*p* value	Whether to accept the assumption
Single threshold	8.2547	0.0200	No
Double threshold	8.1989	0.3367	Yes

Table 5 Threshold regression results

	(1)	(2)	(3)	(4)	(5)	(6)
lnpgdp	0.984***	0.964***	0.970***	1.023***	1.022***	0.993***
	[0.008]	[0.010]	[0.011]	[0.019]	[0.020]	[0.022]
lnpower1	0.885***	0.879***	0.873***	0.904***	0.903***	0.893***
	[0.017]	[0.017]	[0.017]	[0.019]	[0.020]	[0.020]
lnpower2	0.888***	0.881***	0.876***	0.908***	0.908***	0.898***
	[0.016]	[0.016]	[0.016]	[0.019]	[0.019]	[0.019]
lnpop		0.181***	0.189***	0.210***	0.209***	0.173***
		[0.056]	[0.057]	[0.056]	[0.056]	[0.056]
lnpth			−0.023	0.010	0.010	0.013
			[0.020]	[0.022]	[0.022]	[0.021]
lnurb				−0.172***	−0.173***	−0.187***
				[0.052]	[0.052]	[0.052]
lnrd					0.001	−0.003
					[0.006]	[0.006]
lnfin						0.076***
						[0.025]
_cons	−11.342***	−12.212***	−12.320***	−12.512***	−12.483***	−11.705***
	[0.173]	[0.319]	[0.332]	[0.329]	[0.364]	[0.442]
N	234	234	234	234	234	234
R^2	0.988	0.989	0.989	0.989	0.989	0.990

Note: *t* value is in parentheses

***1%, **5%, and *10%-levels of significance

Table 6 Heterogeneity of economic development level

	Low	Medium	High
lnpgdp	0.901***	1.017***	1.364***
	[0.026]	[0.026]	[0.062]
lnpop	−0.045	0.288***	0.064
	[0.041]	[0.087]	[0.081]
lnpower	0.962***	0.952***	0.968***
	[0.027]	[0.021]	[0.034]
lnpth	0.061	−0.063***	−0.111**
	[0.038]	[0.021]	[0.042]
lnurb	−0.072	−0.091	−0.561***
	[0.044]	[0.068]	[0.181]
lnrd	0.007	0.009	−0.012
	[0.006]	[0.008]	[0.020]
lnfin	0.037	0.032	0.126***
	[0.035]	[0.021]	[0.033]
_cons	−10.070***	−13.551***	−14.254***
	[0.454]	[0.613]	[0.682]
N	77	79	78
R^2	0.996	0.994	0.980

Note: *t* value is in parentheses

***1%, **5%, and *10%-levels of significance

Table 7 Heterogeneity of population size

	Low	Medium	High
lnpgdp	0.994***	1.041***	0.762***
	[0.027]	[0.027]	[0.031]
lnpop	0.811***	0.032	−0.173***
	[0.105]	[0.080]	[0.057]
lnpower	1.006***	0.926***	0.862***
	[0.016]	[0.027]	[0.025]
lnpth	−0.013	−0.029	0.151***
	[0.019]	[0.018]	[0.032]
lnurb	0.050	−0.077	−0.008
	[0.089]	[0.087]	[0.053]
lnrd	0.008	−0.017**	−0.006
	[0.008]	[0.007]	[0.007]
lnfin	−0.043*	0.006	0.225***
	[0.022]	[0.018]	[0.035]
_cons	−17.639***	−12.051***	−6.711***
	[0.587]	[0.537]	[0.498]
N	77	79	78
R^2	0.997	0.999	0.996

Note: *t* value is in parentheses

***1%, **5%, and *10%-levels of significance

Table 8 Heterogeneity of energy consumption intensity

	Low	Medium	High
lnpgdp	0.959***	1.144***	1.008***
	[0.030]	[0.026]	[0.019]
lnpop	−0.018	0.405***	0.054
	[0.069]	[0.096]	[0.034]
lnpower	0.745***	0.840***	0.962***
	[0.041]	[0.020]	[0.021]
lnpth	0.048*	−0.015	0.017
	[0.027]	[0.017]	[0.022]
lnurb	−0.209***	−0.507***	0.071
	[0.048]	[0.074]	[0.052]
lnrd	0.001	0.007	−0.010
	[0.007]	[0.007]	[0.006]
lnfin	0.089**	−0.020	−0.014
	[0.038]	[0.021]	[0.025]
_cons	−9.014***	−13.139***	−12.905***
	[0.543]	[0.611]	[0.350]
N	77	79	78
R2	0.997	0.997	0.997

Note: *t* value is in parentheses

***1%, **5%, and *10%-levels of significance

consumption. For population size, urbanization rate, and financial expenditure, as previously analyzed, there are conversions between positive and negative effects in the connection with the total electricity consumption. In the sample of cities with low-energy intensity, increasing population size reduces total electricity consumption in society and vice versa in cities with medium and high energy intensity. The urbanization level shows a negative effect in cities with low and medium energy consumption intensity; however, there is a positive effect in cities with sizable energy consumption intensity. Financial expenditure has a positive effect in a sample of cities with low-energy consumption intensity but has a negative effect in cities with medium and high-energy consumption intensity.

Discussion

Based on the empirical results above, this section discusses the internal mechanism and economic principles in detail, fully demonstrating the relationship between economic and social development and energy consumption in Henan Province, which provides a theoretical basis for the adjustment of the energy structure and the formulation of a power supply strategy in Henan Province.

The results of benchmark regression show that the overall electricity consumption of Henan Province is closely related to economic and social development, which is reflected in all aspects of production and life. As the level of economic development increases, the level of industrialization and the living standards of residents also increase, so the production and consumption of electricity rise (Shiu and Lam 2004). The expansion of the population requires more infrastructure construction, which increases the demand for electricity at the time of construction and for subsequent maintenance. In addition, the spread of smart home systems has led to a large increase in electricity consumption (Liu et al. 2020). The accretion of the level of urbanization has strengthened the agglomeration effect and improved energy efficiency, and total electricity consumption has also fallen (Liu et al. 2018). Expanded government spending means a large number of production and construction projects, which will put considerable pressure on the supply of electricity (Niu et al. 2013). Generally, because of the numerous demands of economic and social development, the general trend of total electricity consumption is constantly increasing, greatly challenging the future power supply of Henan Province.

The results of threshold regression show that there is a nonlinear relationship between economic and social development and energy consumption in Henan Province. The link is likely to be driven by changes in energy consumption levels. When the level of economic development reaches a certain stage, that is, when the threshold is crossed, the energetic effect of energy intensity on electricity consumption is strengthened to a certain extent because one of the main pillars of economic growth is energy; thus, economic growth drives intensive energy use, and as a result, energy end use rises (Hossain 2011). In addition, one of the main engines of economic growth in Henan Province is industry. The improvement of the economic level means the development of industry, and the service industry is also making steady progress, all of which have increased electricity consumption in society from different industrial structural aspects (Yuan et al. 2014). At the same time, residential electricity consumption is the main driving force for the growth of electricity consumption. In areas with more developed economies, the higher income of residents, the greater consumption level, and the increase in consumption patterns all lead to greater electricity consumption.

According to the results of the heterogeneity analysis, it is clear that the relationship between economic and social development and energy consumption is not consistent among cities in Henan Province, and when divided by different indicators, the results vary. The level of economic and social development can affect all aspects of production and life, such as the adequacy of enterprise funds and consumer habits that have a direct impact on the electricity consumption of society (Yuan et al. 2008). The size of the population is related to the demand for electricity for infrastructure and households (Tang 2009). The intensity of energy consumption represents the output level per unit of energy consumption, which is closely related to the structure of industry and the level of technology, and variations in these factors naturally lead to various levels of electricity consumption in different cities (Doms and Dunne 1995). The results of the heterogeneity analysis show that the internal situation in Henan Province is quite complicated. Therefore, it is necessary to consider the unbalanced development of the economy and society in various cities when formulating relevant energy policies.

Policies and recommendations

To explore the link between economic and social development and energy consumption in Henan Province, this paper uses panel data of 18 cities in Henan Province from 2006 to 2018 to conduct an empirical analysis. The results show the following:

1. Based on the STIRPAT model, the main variables related to economic and social development in Henan Province are actively correlated with total electricity consumption. When the levels of economic development, population scale, technology level, and financial expenditure increase, the electricity consumption of Henan Province increases, but the effect of the level of urbanization is the opposite.
2. There is a nonlinear relationship between economic and social development and energy consumption in Henan Province. When the level of economic development is higher than the threshold, the positive effect of energy intensity on electricity consumption is enhanced.
3. At the urban level of Henan Province, the relationship between economic and social development and energy consumption is heterogeneous and is manifested mainly in economic development, population size and energy consumption intensity. In view of the conclusions of this paper, the following policy recommendations are put forward.

    (1) Henan Province should comprehensively consider the relationship between economic and social development and energy consumption. Enterprise production and people's lives are inseparable from a large amount of energy consumption, and electricity as the main end-use energy, which plays a pivotal role in the energy consumption structure, providing an important foundation for the stable operation of the economy and society. The economic and social operational factors are complex and diverse, and China is in a critical stage of industrial restructuring. Because Henan is a province with a large population and economy, its social stability is related to the overall development of the Central Plains. Therefore, Henan Province ought to carry out steadily and orderly grid reform rather than trying to make rice shoots grow faster by pulling them up.

    (2) The adjustment and reformation of Henan's energy system should follow the trend of development. At present, China has entered the era of Internet 2.0, Internet enterprises are developing vigorously, and the new generation of computer technology represented by blockchain technology has become the focus of many industries. The energy industry, as a traditional industry should do, has kept pace with the times, using relevant technology to track energy consumption in real time, accurately taking the pulse of economic and social development, and entering the "Internet +" era.

    (3) Henan Province should create an energy consumption policy in accordance with local conditions. It is necessary not only to formulate and issue unified guidance at the provincial level but also to fully respect the development discrepancies among different cities and conduct a concrete analysis of specific problems. This requires sufficient on-the-spot investigation before the policy is issued. The laws of local economic and social development ought to be fully respected and the relationship between economic and social development and energy consumption should be properly dealt with through a comprehensive study based on indicators such as the level of local economic development, the size of the population and urbanization.

Although this study makes some contributions, there are still some limitations. For example, due to the limited data availability, this study examines the data of Henan Province only from 2006 to 2018; however, economic and social development are long term and cyclical. If we can examine the relationship between economic and social development and energy consumption over a considerable time span, we will surely provide a more detailed and accurate reference for the formulation of future energy policy in Henan Province and developed further research on the basis of this paper.

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Declarations

Ethics approval and consent to participate This article does not contain any studies with human participants or animals performed by any of the authors. All authors consent to participate.

Consent for publication The authors carefully revised and improved the article. All authors consent to publish.

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