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Relationship Between Energy Consumption and Industrial Output-Based on GMM Model of Dynamic Panel Data in China

Dayao Li[1], Faizal Baharum[1,*], Chengguo Jin[2]

[1] School of Housing, Building & Planning, Universiti Sains Malaysia, 11800 Pulau Pinang, Malaysia
[2] Beibu Gulf University, 535000 Qinzhou, China

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ABSTRACT

At present, China is in the historical intersection period of the "two centenary" goals. The realization of the "carbon neutral" goal has brought new opportunities for the development of China's energy sector. Based on the GMM estimation method of the dynamic panel model, this paper studies the relationship between energy consumption and industrial output by using China's provincial data from the years 2008 to 2018. The results show that the impact of coal consumption on industrial output tends to be declining during the sample period. However, compared with other energy consumption, it still dominates a larger proportion. Oil consumption has a negative impact on industrial output with the arrival of a production bottleneck period and the improvement of technology level. As a secondary energy, electricity consumption has an important impact on the industrial output, which is the main energy variable and is significantly positive. Other energy consumption variables have significant positive effects on industrial output. In this paper, we obtain countermeasures and suggestions on energy, such as giving full play to the decisive role of the market, improving the innovation environment in the field of energy, speed up the transformation of new and old kinetic energy.

1. Introduction

Industrial growth is one of the important driving forces for sustained and stable economic growth. Energy is the “food” of industry and an important material basis for economic development [1-2]. In the short term, under the constraints of world energy supply and demand and ecological environment, the change of energy structure can not only inhibit economic growth but also promote economic growth [3-4]. Therefore, the correct analysis of the relationship between energy consumption and industrial output has important theoretical and practical significance for the rational use of energy and sustained and stable economic growth.

* *Corresponding author.*
E-mail address: baharumfaizal@gmail.com

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Based on the error correction model, Aslan et al. discussed the dynamic image relationship between energy consumption and GDP in the United States, and the study showed that energy consumption in the United States significantly promoted economic growth [5].

Applying the panel data model to the study of the relationship between energy consumption and economic growth has become a hot topic in the field of the domestic energy economy in China. H. Li et al. studied the relationship between China's energy consumption and economic growth based on the Granger causality test model, and found that economic growth and energy consumption have a strong dependence, and the two show the characteristics of a nonlinear relationship [6]. Tian, X., et al. studied the relationship between economic growth and energy consumption of 10 major countries in the world based on the fixed effect model. The results showed that the consumption of oil, coal, natural gas, and nuclear energy significantly promoted the economic growth of sample countries [7]. Based on the lstvar model, Dong, Y used the GIRF impulse response function to study the relationship between industrial production activities and energy consumption in different development stages in China. The results show that, in different development stages, industrial economic growth shows a strong dependence on energy consumption [8].

Some countries and regions also give us good enlightenment and broad ideas in the development and application of energy. Denmark is becoming one of the forerunners. In Denmark, the government implements 100% renewable energy policies and leads to the challenge of balancing electricity supply and demand and reaching a goal to use bioenergy and 100% of renewable energy for transportation systems [9]. D. Connolly et al. presented one scenario for a 100% renewable energy system in Europe by the year 2050 [10]. The transition from a business-as-usual situation in 2050, to a 100% renewable energy Europe is analyzed in a series of steps. For each step, the impact is presented in terms of energy (primary energy supply), environment (carbon dioxide emissions), and economy (total annual socio-economic cost). Siir Kılkıs et al. [11] provided a review of recent scientific contributions in energy system integration, urban synergies in the energy transition, integration of energy and water systems as well as valorization of waste heat.

To sum up, based on the above research literature on the relationship between energy consumption and economic growth in the world, we can see that scholars have done a lot of research on the relationship between energy consumption and economic growth. But there is less research on the relationship between energy consumption and industrial output[12]. As we all know, industry is an important support for economic development. Energy consumption have a closer and direct relationship with industrial output compared with energy consumption and economic growth. It has been repeatedly mentioned and studied by scholars all over the world whether there is any internal relationship between industry and energy consumption. Scholars all over the world generally use stationarity test, cointegration test and granger test to test the relationship between industry and energy consumption, but most of the samples are time series data, and the panel data model is relatively small. Therefore, further quantitative research on the relationship between energy consumption and industrial entanglement has more practical significance for industrial analysis and policy-making. Moreover, most of the current researches on energy consumption focus on the relationship between energy consumption and GDP of the whole country or region. That is to say, research on the economic level of the whole country or region. However, there are few studies on the relationship between energy consumption and a specific industry, such as the relationship between energy consumption and industry, the relationship between energy consumption and agriculture. These studies on the relationship between total energy consumption and economic growth have not played a particularly good representative role for a single industry. As the industrial sector consumes nearly 70% of China's energy resources, it is of great significance to study the relationship between industrial energy consumption and output, which can provide a strong empirical basis for the formulation of scientific and effective industrial energy policy. China is a big energy country, and its energy utilization will play an important role in the sustainable development of the world energy. Based on this, we studies China's energy consumption from the perspective of industrial output, in order to provide useful enlightenment for the relevant industry analysis and policy implementation.

2. Methodology

2.1 Data Source and Samples

We selects the provincial panel data of China（2008-2018）as the sample for the survey period to estimate[13-14]. In view of the availability of the data, the provinces such as Tibet, Ningxia, Guizhou and Qinghai provinces which lack more data are excluded. Therefore, the sample data of this paper consists of 27 provinces, cities and autonomous regions in China. The data are collected from China Statistical Yearbook（2008-2018）, China Industrial statistical yearbook（2008-2018）and China energy statistical yearbook（2008-2018）.

2.2 Research Model

The general dynamic panel model is considered:

$$y_{it} = \alpha + \rho y_{i,t-1} + x_{it}^{`}\beta + z_i^{`}\delta + u_i + \varepsilon_{it} \quad (t = 2,...,T) \tag{1}$$

By eliminating the individual effect by first-order difference, the differential GMM model can be obtained:

$$\Delta y_{it} = \rho \Delta y_{i,t-1} + \Delta x_{it}^{`}\beta + \Delta\varepsilon_{it} \; (t = 2,...,T) \tag{2}$$

$$Cov(\varepsilon_{it}, \varepsilon_{is}) = 0, t \neq 0, \forall i.$$

Blundell et al. put the horizontal equation and difference equation into the same equation system for estimation, and obtained the GMM model of the system[15].

$$y_{it} = \alpha + \rho_1 y_{i,t-1} + \rho_2 y_{i,t-2} + ... + \rho_p y_{i,t-p} + x_{it}^{`}\beta + z_i^{`}\delta + u_i + \varepsilon_{it} \tag{3}$$

Acemoglu, D., et al. based on the dynamic panel data differential GMM estimation, found that the explanatory variables had no significant effect on the explained variables[16]. Che, Y., based on GMM Estimation of dynamic panel data system, using the same data, the opposite conclusion is obtained. Che, Y., thinks that the differential GMM estimation method has the problem of weak instrumental variables, while the systematic GMM estimation method is relatively more efficient[17].

Based on this, this paper uses the difference GMM and System GMM to compare the estimation, and uses the method of gradually adding variables to ensure the robustness of the model estimation results.

$$y_{it} = \alpha + \beta_0 y_{it-1} + \beta_1 co_{it} + \beta_2 pe_{it} + \beta_3 po_{it} + \beta_4 ot + \mu_i + \varepsilon_{it} \tag{4}$$

In Formula (4), "i" is the ith Province, city and autonomous region, "t" is the year, "ui" is the unobservable individual effect that does not change with time, and ε it is the random error term.

3. Results

3.1 Fluctuation Analysis of Energy Consumption and Industrial Output

Energy industry, also known as fuel power industry, refers to the development and utilization of natural energy resources and the transformation of secondary energy industry. Energy Industry is one of the advanced industrial sectors in the development of national economy. It plays a very important role in the development of national economy. Based on China's energy consumption data, this paper analyses the fluctuation trend of China's energy consumption and industrial output from the year 1998 to 2018.

The energy consumption elasticity coefficient, also known as energy consumption growth coefficient, is an important technical and economic index reflecting the relationship between energy and economic development [18-19]. Its calculation formula is as follows:

$$e = \frac{\text{Growth rate of energy consumption}}{\text{economic growth rate}} = \frac{dE / E}{dy / y} \qquad (5)$$

In Formula (5), "e" is the energy consumption elasticity coefficient. The smaller the energy consumption elasticity coefficient is, the smaller the energy consumption per unit of output. In contrast, the greater the energy consumption elasticity coefficient is, the greater the energy consumption per unit of output. In the short term, as the economic and technical conditions of a country or region will not change much, the elasticity coefficient of energy consumption is usually relatively stable. Generally speaking, the energy utilization efficiency of a country or region is relatively low at the initial stage of development. Therefore, the energy consumption elasticity coefficient of developing countries is usually greater than or close to 1, while the energy consumption elasticity coefficient of developed countries is usually less than 0.5.

3.1.1 Analysis of energy consumption elasticity coefficient

Energy consumption elasticity coefficient is a result and comprehensive index to measure the quality of a country's economic development and the transformation of its development mode. It has obvious characteristics of stage change, which is suitable for the stage characteristics of economic development, and is closely related to GDP growth rate, industrial structure change, economic development quality and other factors in different stages. Based on the energy consumption data of China from the year 1998 to 2018, we can analyses the energy elasticity coefficient of China and observe the energy consumption per unit output. It can be seen from Fig.1 that the elasticity coefficient of China's energy consumption shows cyclical changes during the year 1998 to 2018. It can be divided into three stages.

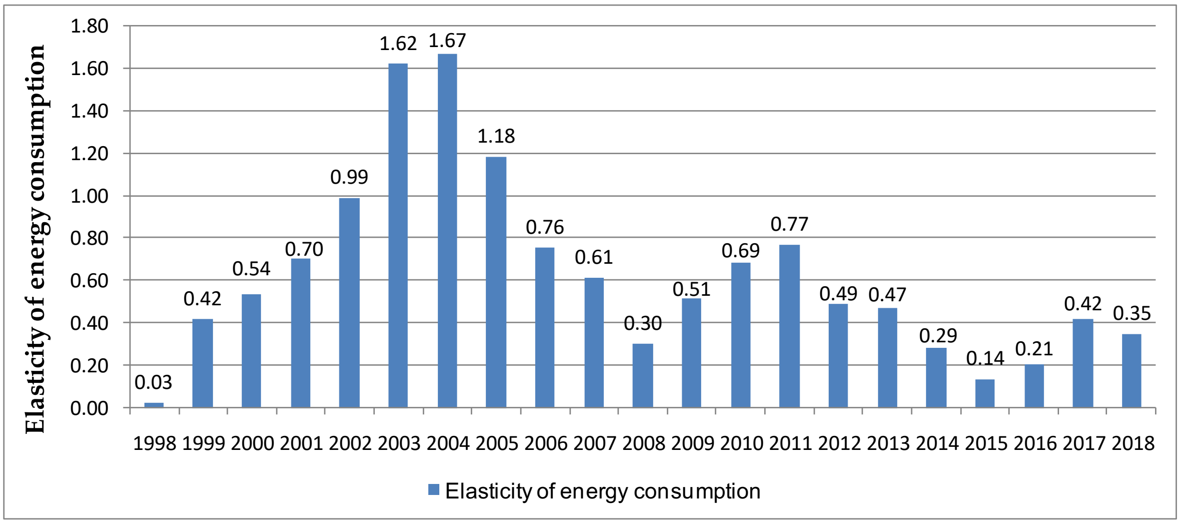

Fig. 1. Elasticity of energy consumption

The first stage is from the year 1998 to 2007, in this stage the minimum value of 0.03, which appeared in 1998 after the Asian financial crisis in the year 1997, which is the first trough in the sample cycle. The maximum value was 1.67, which appeared in the year 2004, which was the first peak in the sample period. Correspondingly, the growth rate of energy consumption in 2004 reached 16.8%, which was the maximum growth rate in the sample period. During this period, the average annual growth rate of China's economy remained at a high level of 10.8%. The growing demand is mainly driven by the acceleration of industrialization, the growth of net exports, and the promotion of urbanization. The main driving force of the growth comes from the extensive growth of scale input of energy, labour and other factors, which is represented by the secondary industry with high energy consumption. The mode of economic development at this stage determines that GDP growth has a high degree of dependence on energy and other factors. The second stage is from the year 2008 to 2012, during the subprime mortgage crisis in the year 2008, the second trough appeared, and the elasticity coefficient of energy consumption was 0.30. The second peak appeared in the year 2011, and the elasticity coefficient of energy consumption was 0.77. At this stage, under the influence of changes in the external environment, China's GDP growth showed a downward trend, with an average annual growth rate of 9%. The traditional demand for net exports and investment shows a rapid decline, and the growth rate of the secondary industry has slowed down. However, under the stimulation of China's "steady growth" measures, the high-energy consumption industry still has a high growth rate. The third stage is from the year 2013 to 2018. After China entered the new normal of economic growth in the year 2013, a series of energy-saving and emission-reduction measures were implemented. The elasticity coefficient of energy consumption in the year 2013 to 2018 was less than 0.5. The reason for this is that on the one hand, the growth rate of energy consumption slows down, on the other hand, it also reflects the continuous improvement of energy utilization efficiency with the adjustment of economic structure. At this stage, China's economic growth has been adjusted from high-speed growth to medium high-speed growth, with an average annual GDP growth rate of about 7%. China's economic development has entered a stage of high-quality economic development. The demand structure has shifted from net export and investment-driven to a new normal dominated by investment and consumption. The driving force of growth has continued to shift, and scientific and technological innovation has promoted the steady improvement of TFP, the growth effect brought by the scale input of production factors has gradually weakened, the pattern of industrial structure has undergone major changes, and the dependence of economic growth on energy consumption has decreased significantly.

On the whole, in the period of high economic growth, factor input is the main power source of economic growth, and the rapid growth of high energy-consuming industries keeps the energy consumption elasticity coefficient at a high level. In the new normal stage of economic growth, technological innovation and the improvement of TFP become new power sources, and the elasticity coefficient of energy consumption drops to a low level. The relationship between the two shows a state of "relative decoupling".

3.1.2 Growth rate of industrial output analysis

According to Fig.2, the average annual growth rate of industrial output is 18.8% in the sample period from 1998 to 2018. The largest growth rate was 32.9% in 2001. The first growth rate of less than 10% was 8.1% in 2009 after the subprime crisis. After entering the economic new normal in 2013, the growth rate of industrial output shows a downward trend year by year, and the growth rate in 2017 is - 2.2%, which is the minimum value in the sample period.

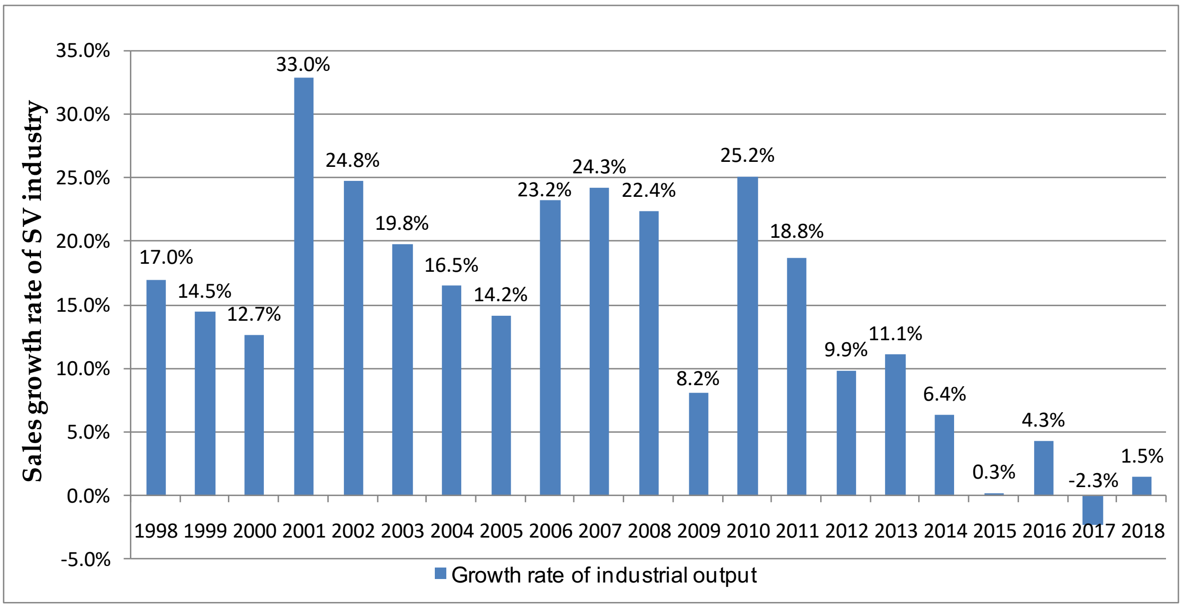

Fig. 2. Sales growth rate of SV industry

Over the past 40 years of reform and opening up, China has not only become a big manufacturing country in the world, but also a country with all the industrial categories in the United Nations industrial classification catalogue. However, while China has made great progress on the road of industrialization, it is also facing unprecedented challenges. As we all know, industrial production is a kind of production of mining and utilizing material resources, which determines the limitations of industrial development [23]. First, when industrialization develops to a certain extent, natural resources will inevitably show a shortage, and even lead to a global resource crisis to certain extent. Second, while promoting social progress, industrial production has caused pollution and damage to the ecological environment. Third, with the rapid development of emerging industries in recent years, the traditional market space of industrialization is gradually converging [24].

With the gradual rise of China's resources, environment, labour, and land costs, the low-cost advantage in the early stage of industrial development has decreased significantly. As far as the whole process of industrialization is concerned, China is now in the process of transformation from industrialization to post-industrialization. The mode of growth is changing from extensive development to high-quality green development. The natural environment, material resources and market space will inevitably become the constraints of future industrial development. From a macro perspective, we can find that the economy has entered the stage of high-quality development with medium and high-speed growth. The transformation of the development mode has a profound impact on the production structure and energy structure [25].

3.2 Unit Root Test

We select the provincial panel data of China（2008-2018）as the sample for the survey period to estimate. In view of the availability of the data, the provinces such as Tibet, Ningxia, Guizhou and Qinghai provinces which lack more data are excluded. Therefore, the sample data of this paper consists of 27 provinces, cities, and autonomous regions in China. The specific index definition and statistical description are shown in Table 1 and Table 2.

Table 1
Definition of indicators

Type	Symbol	Meaning	Unit	Sample period	Frequency
Explained variable	Y	Coal consumption	Million tons		
Explanatory variable	CO	Oil consumption	Million tons		
Explanatory variable	PE	Electricity consumption	Million tons	2008-2018	Year
	PO	Industrial sales value	Ten thousand tons of standard coal		
	OT	Other energy consumption	Ten thousand tons of standard coal		

Table 2
Statistical results of sample description

Variable	Mean	Std. Dev.	Min	Max	Obs
Y（Industrial sales value）	0.095	0.114	-0.392	0.351	216
CO（Coal）	0.005	0.142	-0.797	0.776	216
PE（Oil）	0.080	0.120	-0.518	0.698	216
P（Electricity）	0.069	0.070	-0.223	0.333	216
OT（Other energy）	0.025	0.960	-4.330	6.109	216
Y（Industrial sales value）	0.095	0.114	-0.392	0.351	216

Before the estimation of panel data model, in order to avoid the phenomenon of "pseudo regression", it is necessary to test the stationarity of each variable[20-21]. The use of non-stationary variables for panel data model estimation cannot accurately describe the logical relationship between variables[22]. Based on the applicability of various test methods, LLC, IPS and HT three unit root test methods are selected to test. The results are shown in Table 3.

Table 3
Statistical results of sample description

Test method	Y	CO	PE	PO	OT
LLC	-16.821***	-6.253***	-11.052***	-17.460***	-42.119***
IPS	-2.627***	-3.411***	-4.874***	-3.638***	-4.881***
HT	0.585**	-0.213***	-0.077***	0.068***	-0.222***

Notes: the results of the LLC test and IPS test correspond to the t statistic value, and the HT test result corresponds to the Rho statistic value.

Table 3 shows that each variable has passed the significance test at the level of 5% under the three-panel data unit tracking test methods, that is, it has passed the stationarity test.

3.3 GMM Model Estimation and Result Analysis

The AR (2) and P value of sargan test were used to verify the autocorrelation of residual sequence and over-identification of instrumental variables. It can be seen from Table 4 that the AR (2) test results of all models are greater than 0.05, that is, there is no autocorrelation of the second-order residual term. Meanwhile, the test results of sargan test are all greater than 0.05, which supports the reliability of the model estimation results.

Table 4
Estimation results of GMM model

Variable	Model 1		Model 2		Model 3		Model 4	
	Difference	System	Difference	System	Difference	System	Difference	System
Y1.	0.598***	0.596***	0.603***	0.604***	0.550***	0.547***	0.551***	0.558***
	（0.000）	（0.003）	（0.007）	（0.004）	（0.022）	（0.019）	（0.021）	（0.018）
CO	0.042***	0.052***	0.041***	0.042***	0.044***	0.042***	0.034***	0.029***
	（0.015）	（0.009）	（0.010）	（0.007）	（0.004）	（0.007）	（0.005）	（0.008）
PE			-0.041***	-0.081***	-0.057***	-0.088***	-0.068***	-0.101***
			（0.017）	（0.005）	（0.021）	（0.016）	（0.023）	（0.018）
PO					0.352***	0.387***	0.359***	0.422***
					（0.027）	（0.029）	（0.026）	（0.031）
OT							0.009***	0.013***
							（0.001）	（0.002）
_cons	0.006***	0.006***	0.008***	0.012***	-0.004***	-0.004***	-0.005***	-0.007***
	（0.001）	（0.001）	（0.001）	（0.000）	（0.001）	（0.002）	（0.001）	（0.001）
AR(1)	0.000	0.000	0.001	0.001	0.000	0.000	0.000	0.000
AR(2)	0.113	0.103	0.092	0.079	0.083	0.085	0.077	0.076
Sargan	0.180	0.435	0.177	0.461	0.275	0.601	0.276	0.692

Notes: * *, * *, and * represent rejection of the original hypothesis at the significance level of 1%, 5% and 10%, respectively. The values in brackets are standard errors, and AR and sargan are the corresponding P values.

The overall estimation results of the four groups of models show that, on the one hand, except for the oil variables, there is no significant difference between the estimation results of other variables in the differential GMM model and the System GMM model. On the other hand, the results also show that the estimation results of each group of models are more robust, based on the previous research results of differential GMM and System GMM models. In the following, the paper will analyse the estimation results of the GMM model in model 4 of Table 4.

First of all, we observe the lagged first stage variable L1 of industrial output. It can be seen that China's industrial output is closely related to the previous energy input. The value of output affected by the previous energy input reaches 0.558, which is significantly positive at the level of 1%.

Secondly, considering the estimation results of each variable, coal consumption increases by one unit, and industrial output increases by 0.029 units. And it is significantly positive at the level of 1%. Among the energy variables, the impact on output is second only to the electric power variable, but the gap with other variables is relatively small. This may be due to the fact that China's coal supply reached a peak of 3.97 billion tons in 2013, and the absolute output dropped sharply from 2014-2016. At the same time, the coal industry has entered the structural optimization and adjustment period of low emission utilization and emission cleaning.

The impact of oil variables on industrial output is -0.101, and it is significantly negative at the level of 1%. The reason may be that, on the one hand, China's oil industry has entered the bottleneck period since 2010, and the main large oil fields have entered the late stage of development, and the output has decreased year by year. On the other hand, with the improvement of technology and management levels, the oil utilization efficiency is improved, and the relative level of dependence on oil is reduced.

It is worth noting that the impact of electricity as a secondary energy on industrial output reaches 0.422, which is significantly positive at the level of 1%. The main reason is that China's electric power has entered a period of rapid growth since 2000. By the year 2017, the installed capacity of electric power has increased by 4.3 times, with an average annual increase of nearly 90 million kilowatt hours, 3.4 times, and an average annual increase of nearly 310 billion kwh The power supply has formed a relatively stable supporting role for industrial output. When other energy variables increase one unit supply, industrial output increases by 0.013, which is less than the positive impact of coal and oil on industrial output. The reason may be that with the development of new energy, renewable energy and other utilization technologies, the development and utilization efficiency of other energy sources are constantly improved.

4. Conclusions

Based on the GMM estimation method of dynamic panel model, this paper studies the relationship between energy consumption and industrial output by using China's provincial data from the year 2008 to 2018. Through the above analysis we get the following conclusion.

4.1 Analysis Results

(1) The impact of coal consumption on industrial output tends to be weakened during the sample period. But compared with other energy consumption, it still occupies a larger proportion and is significantly positive.

(2) Oil consumption has a negative impact on industrial output with the arrival of production bottleneck period and the improvement of technology level.

(3) As a secondary energy, electricity consumption has an important impact on the industrial output which is the main energy variable in the energy variables selected in this paper. And it is significantly positive.

(4) Other energy consumption variables have significant positive effects on industrial output.

4.2 Policy Suggestions
4.2.1 Give full play to the decisive role of the market

Energy price is an important factor affecting energy consumption. We should further promote the benign formation mechanism of energy price and give full play to the decisive role of price mechanism in resource allocation. At present, except for coal price, the price of other energy products is under strict government supervision in China, which fails to form energy price which fully reflects the relationship between supply and demand and the degree of resource scarcity. Therefore, we should further promote the market-oriented reform of energy prices, build up the market determined prices and the energy price formation mechanism effectively regulated by the government, regulate market supply and demand through price mechanism, and promote energy conservation and emission reduction.

4.2.2 Improving the innovation environment in the field of energy

Take the innovation driven development strategy as an opportunity to improve the support policies and innovation environment in the energy field. Through fiscal and tax policies, special funds and innovation support, industrial enterprises are encouraged to conduct international exchanges and cooperation in the fields of carbon emission technology and clean energy development. Promote the introduction, absorption and re innovation of technology, activate the R & D and innovation vitality and potential of industrial enterprises, so as to promote the improvement of industrial production efficiency and reduce the demand and consumption of energy. At the same time, we should build an ecosystem of innovation network and technological innovation, and promote the "network chain" connection and deep interaction between innovation subjects.

4.2.3 Speed up the transformation of new and old kinetic energy

It is suggested to deepen the supply side structural reform, implement strict reform and elimination policies for the "old kinetic energy", and eliminate all kinds of improper tax incentives and subsidies. To avoid the production capacity that should have been eliminated, we should further increase energy input to maintain profits, which will lead to excessive energy consumption, promote the improvement of total factor energy efficiency, and transform it into "new kinetic energy". Through various economic levers, we can adjust, guide and smooth the injection path of social resources into "new kinetic energy", promote the rapid growth of new technologies and new industries, cultivate "new kinetic energy" and accelerate the development.

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