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Research on Internal Substitution of Industrial Energy in China under the Background of Energy Transformation

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Abstract

In this paper, the internal elasticity of energy substitution in China's industry and 36 industries was measured by TCL function from 1995 to 2015. It is found that the internal substitution of energy is feasible, in which the substitution effect of electricity, oil and coal is relatively low in the whole industry, but there is a great prospect for the substitution of electricity and oil for coal in some industries. At the same time, the substitution of clean energy for coal and other traditional fossil energy must be accelerated. Therefore, in the critical period of China's energy transformation, in order to achieve the established energy development goals as soon as possible, China needs to promote the reform of energy price system in accordance with the future direction of energy substitution, improve the energy consumption structure through energy substitution, and improve the energy use efficiency.

Keywords

Energy Transition; Energy Substitution Elasticity; TCL Function.

1. Introduction

At present, China's rapid economic development, energy demand has been greatly increased, which has brought about serious resource shortage and environmental pollution, and the fundamental reason for this situation is the unreasonable energy structure and low energy efficiency. China's Energy Production and Consumption Revolution Strategy (2016-2030), released in 2016, clearly outlined the development goals of the energy revolution, marking the acceleration of China's energy revolution. Generally speaking, there are three fundamental measures for energy conservation and emission reduction: reducing fossil energy consumption, adjusting energy structure and low-carbon technology innovation. "Rigid demand" exists because of the economic growth of energy, so the short-term energy consumption in developing countries would continue to increase, in addition of low carbon technology innovation in the short term will not make huge progress, so in view of the developing countries more natural weight reduction falls in the adjustment of energy structure, use low-carbon clean energy instead of the high carbon energy. Therefore, from the perspective of energy substitution, we can provide theoretical support for China to improve energy structure and energy efficiency by measuring the elasticity of internal substitution of energy.

In microeconomics, whether energy, as an input factor, can be replaced by other factors and whether there is mutual substitution between different types of energy, is directly related to the choice of a country's energy development strategy. Since Hicks put forward the concept of substitution elasticity in 1932, the substitution theory of elements has been widely developed and applied[1]. Zhang Yuzhuo from energy price policy perspective, on the two different kinds of energy in the same market price game analysis, think different, between the price of energy supply in the cost and the influence of its function is also affected by the other energy related parameters, once again confirm the internal replacement may affect the energy consumption structure of energy[2]. Hang leiming made an empirical study on the relationship between

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China's manufacturing industry, energy prices and energy intensity, and found that the rise of relative energy prices has a positive contribution to the reduction of total energy intensity, oil intensity, power intensity and coal intensity[3]. Shi Hongliang et al. paid further attention to the steel industry with high energy consumption in China. They believed that the substitution elasticity of coal, oil, natural gas and electricity was about 1, and the substitution effect was obvious. They believed that the steel industry could effectively use clean energy to replace coal, so as to optimize the industrial energy structure[4].

However, there are still shortcomings in previous studies. First, although the commonly used AES substitution elasticity can better measure the absolute value of substitution elasticity among factors, it cannot reflect the asymmetry of substitution elasticity of factors, while the less used price substitution elasticity is more effective because it takes into account the output effect of factors and has asymmetry. So, this paper calculates the cross-price substitution elasticity and self-price elasticity between energy sources (including coal, oil and electricity) of China's industrial sectors from 1995 to 2015 based on the TCL function.

2. Methodology

2.1. Econometric Model

On the basis of the asymmetric effect of energy and capital in China's manufacturing industry[5], this paper still chooses the TCL function to study the problem of energy substitution. The specific function form is as follows:

$$\begin{aligned}\ln C = \alpha_0 + \alpha_y \ln Y_t + 0.5\alpha_{yy}(\ln Y_t)^2 + \alpha_t T + 0.5\alpha_{tt}(T)^2 + \sum_i \delta_i \ln Y_t \ln P_i + \\ \alpha_{yt} \ln Y_t T + \sum_i \beta_i T \ln P_i + \sum_i \alpha_i \ln P_i + 0.5\sum_i \sum_j \gamma_{ij} \ln P_i \ln P_j\end{aligned} \quad (1)$$

α_0, $\alpha_y, \alpha_{yy}, \alpha_t, \alpha_{tt}, \alpha_{yt}, \alpha_i, \delta_i, \beta_i$ and γ_{ij} represents the relevant estimated parameters of the TCL function. C is the average total cost. Y_t is the output of time t. P_i and P_j indicates the price of the i and j energy sources, and t is the time trend of measuring technological change. The function satisfies the symmetry condition, $\gamma_{ij} = \gamma_{ji}$. According to Shephard's lemma, the partial derivative of the logarithm of the price of a single energy source is obtained from both sides of the equation (1), and the cost share equation of a single energy source is obtained.

$$S_i = \frac{\partial \ln C}{\partial \ln P_i} = \alpha_i + \delta_i \ln Y_t + \beta_i T + \sum_i \gamma_{ij} \ln P_j \quad (2)$$

Where S_i represents the I (i = 1.2... n) cost share of various energy sources, where δ_i and β_i respectively describe the change of the cost share with technological progress and economic output. Since the sum of all the cost share equations must be equal to 1, each parameter satisfies the following constraints:

$$\sum_i \alpha_i = 1, \sum_i \delta_i = \sum_i \beta_i = 0, \sum_i \gamma_{ij} = \sum_j \gamma_{ij} = 0 \quad (3)$$

Under the constraint conditions of Eq. (3), the cost share equations of Eq. (2) can be systematically estimated to obtain the relevant parameters, and then the sum of cross-price substitution elasticity and the self-price elasticity evolved on this basis are calculated in this paper. It has been mentioned in a large number of literatures that the cross-price substitution elasticity (CPE) η_{ij} between energy sources refers to the amount of change in the demand for energy i caused by the price change of energy j, and the self-price elasticity (OPE) η_{ii} of energy sources refers to the amount of change in its own demand caused by the price change of energy I, which can be calculated as follows:

$$\eta_{ij} = \frac{\gamma_{ij}}{S_i} + S_j, i \neq j, \eta_{ii} = \frac{\gamma_{ij}}{S_i} + S_i - 1 \quad (4)$$

If the substitution elasticity is positive, it means that the energy substitutes each other, that is, the price of one energy increases, the demand for the other energy increases, and the higher the value η_{ij} is, the greater the elasticity is, and the more obvious the substitution effect will be. They are completely different from each other. If the value is negative, it means that there is a complementary relationship between energy sources, and the increase in the price of one energy source will lead to a decrease in the market demand for the other energy source, and the greater the absolute value η_{ij} of is, the more significant the complementary effect will be. In other words, we must first calculate the cost share of each energy, then systematically estimate the cost share equations, and finally calculate the internal elasticity of substitution of energy.

2.2. Data Source and Processing

Due to the lack of some data, the research object of this paper is 36 industrial industries. The index of industrial output by sector is measured by industrial added value, with data from China Statistical Yearbook. The index takes 1995 as the base period, and then calculates the added value by sector in 1995 according to "ex-factory price index of industrial products by sector". the index of industrial output by sector is measured by industrial added value, with data from China Statistical Yearbook. The index takes 1995 as the base period, and then calculates the added value by sector in 1995 according to "ex-factory price index of industrial products by sector". This paper adopts an energy consumption industry, at the same time, industrial electricity prices from China power statistical yearbook, the price of coal from Wind an unwinding of Qinhuangdao thermal coal price, the price of oil from BP's approximation of the international average price of oil, energy prices can be the real price of a certain year energy and energy price index to calculate. Therefore, this paper calculates based on the actual energy prices in 2015 and the energy price index released by the state.

3. Results

First, the cost of each energy source can be calculated based on the price and consumption of each energy source. Secondly, independent BP test is conducted to reject the null hypothesis according to the cost share equations composed of the three energy sources. Finally, the elasticity of substitution between energy sources is estimated by using quasi-uncorrelated regression. The estimated parameter results of the cost share equation for the three energy sources are listed in the following Table:

Then according to the parameter estimation results in Table 1, the cross-price substitution elasticity and self-price elasticity of Equation (4) are calculated. The results of inter-energy substitution elasticity are listed in the following table:

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Table 1. Parameter estimation results of cost share equation of each energy source

Coal		electricity		oil	
φ_{C-C}	0.1874*** (0.0145)	φ_{E-E}	-0.1467*** (0.0179)	φ_{O-O}	0.1065
φ_{C-E}	-0.1137*** (0.0117)	φ_{E-C}	-0.1137* (0.0117)	φ_{O-C}	-0.0737*
φ_{C-O}	0.0736*** (0.0145)	φ_{E-O}	-0.0329*** (0.0150)	φ_{O-E}	-0.0330*
$\varphi_{C,T}$	0.1874*** (0.0132)	$\varphi_{E,T}$	0.0126*** (0.0009)	$\varphi_{O,T}$	-0.007**
φ_{C}	0.5664*** (0.0748)	φ_{E}	1.5732*** (0.1145)	φ_{O}	-0.0068*
R^2	0.9209	R^2	0.8930	R^2	-

Table 2. Internal elasticity of substitution of energy in industry as a whole and by industry

Industry code	η_{CC}	η_{CE}	η_{CO}	η_{EE}	η_{EC}	η_{EO}	η_{OO}	η_{OC}	η_{OE}
Overall industry	-0.481	0.188	0.373	-0.347	0.103	0.245	-0.482	0.285	0.197
6	-0.437	0.134	0.102	-0.294	0.273	0.021	-0.447	0.355	0.091
7	-0.448	0.110	0.237	-0.249	0.065	0.184	-0.545	0.156	0.390
8	-0.261	0.127	0.034	-0.347	0.446	-0.099	0.242	0.520	-0.763
9	-0.084	0.162	0.177	-0.161	0.025	0.186	-0.549	0.045	0.503
10	-0.169	0.103	0.116	-0.115	0.006	0.109	-0.535	0.060	0.474
13	-0.635	0.064	0.029	-0.056	0.034	0.090	-0.509	0.008	0.501
14	-0.120	0.079	0.059	-0.066	0.014	0.080	-0.496	0.027	0.469
15	-0.481	0.073	0.102	-0.234	0.193	0.041	-0.457	0.257	0.200
16	-0.462	0.156	0.106	-0.269	0.235	0.034	-0.461	0.310	0.151
17	-0.260	0.011	0.149	-0.148	0.016	0.131	-0.548	0.079	0.469
18	-0.330	0.069	0.160	-0.164	0.030	0.134	-0.549	0.029	0.453
19	-0.301	0.017	0.116	-0.117	0.030	0.146	-0.550	0.029	0.521
20	-0.283	0.120	0.163	-0.160	0.019	0.141	-0.550	0.085	0.465
21	-0.486	0.023	0.063	-0.187	0.176	0.011	-0.300	0.210	0.090
22	-0.097	0.129	0.033	-0.044	0.010	0.054	-0428	0.019	0.409
23	-0.212	0.121	0.009	-0.026	0.015	0.040	-0.371	0.006	0.365
24	-0.411	0.174	0.138	-0.329	0.291	0.039	-0.513	0.406	0.108
25	-0.486	0.117	0.168	-0.243	0.134	0.109	-0.545	0.216	0.329
26	-0.237	0.137	0.100	-0.106	0.018	0.088	-0.513	0.067	0.446

27	-0.441	0.391	0.050	-0.258	0.279	-0.021	-0.128	0.313	-0.185
28	-0.130	0.082	0.838	-0.157	2.862	1.296	-0.048	0.078	0.030
29	-1.374	0.065	0.591	-0.282	0.264	0.546	-0.171	0.022	0.150
30	-0.100	0.185	0.085	-0.088	0.015	0.103	-0.527	0.034	0.494
31	-0.310	0.204	0.106	-0.347	0.379	0.032	-0.446	0.533	0.087
32	-0.243	0.189	0.054	-0.340	0.241	-0.100	-0.125	0.578	0.454
33	-3.071	0.196	0.279	-0.075	0.047	0.028	-1.634	0.235	1.398
34	-0.478	0.123	0.355	-0.331	0.065	0.266	-0.489	0.201	0.288
35	-0.298	0.127	0.071	-0.088	0.033	0.056	-0.446	0.069	0.377
37	-0.443	0.193	0.049	-0.256	0.276	0.020	-0.127	0.309	0.182
38	-0.380	0.162	0.018	-0.059	0.061	0.020	-0.012	0.046	0.034
39	-0.424	0.190	0.133	-0.165	0.067	0.097	-0.530	0.128	0.402
40	-0.460	0.105	0.055	-0.122	0.103	0.019	-0.300	0.127	0.174
44	-0486	0.112	0.074	-0.178	0.152	0.025	-0.372	0.193	0.179
45	-0.452	0.193	0.159	-0.197	0.082	0.115	-0.544	0.152	0.392
46	-0.379	0.169	0.110	-0.134	0.051	0.083	-0.510	0.103	0.407

At the industrial level as a whole, the self-price elasticity of each energy source is negative, that is, the demand for energy decreases as the price rises. At the same time, the absolute value of substitution elasticity of electric power is less than that of coal and oil, indicating that the electric power demand is less affected by the change of electricity price, and the electric power demand is more rigid than that of coal and oil, which is in line with the actual situation of accelerating the reform process of electricity price in China. At the same time, the cross-price elasticity of electricity, coal and oil is positive, indicating that they are substitutes. This finding is of great significance to improve the energy structure through energy substitution. If coal can be replaced with electricity and oil, it means that Chinese industry has the potential to shift from high-emission coal to cleaner energy sources such as hydropower and wind power. However, it is also found from Table 2 that the cross-price elasticity of all energy sources is less than 1, indicating that when the price of one energy source rises, the demand for another energy source will increase, but it will not completely replace the use of another energy source. This limits the effect of promoting internal energy substitution through energy pricing policies to a certain extent. Such as raising the price of coal or lower the price of electricity can effectively reduce the use of coal, and increase of electricity consumption, which to some extent to achieve the power of substitution of coal, can effectively improve the energy structure problems in our country, but as the economic output unchanged, may need a sharp change of coal or replace coal power price can realize power significantly, So the substitution effect is limited.

Unless alternative on coal for electricity, metal mining and dressing industry above the level of the overall industry, the rest of the industry is less than 0.188, the substitution effect is low, the plastics and rubber manufacturing industry, chemical fiber industry, agricultural and sideline food processing and other nine industry substitution effect is below 0.1, shows that this kind of strong dependence on coal industry, still there is greater demand for coal. Observe the substitution of coal by electricity. Nonferrous metal smelting and rolling processing industry, ferrous metal mining and processing industry, chemical fiber manufacturing industry, the substitution elasticity of these three industries is all greater than 0.4, that is, when the coal price rises, in order to keep the output unchanged, the electricity consumption will increase, thereby reducing the use of coal. So when considering the substitution effect of electricity and coal, can see that the industry overall level is low, and this is mainly due to the part of the industry of coal "rigid demand", and the industry the industrial added value of industrial added value of the total proportion of larger, therefore the overall industrial replacement level was not significant, but individual industry still has great elasticity of substitution, This finding indicates that there is great potential for this type of industry in China to use electricity instead of coal. Therefore, increasing the price of coal and reducing the price of electricity for such industries can effectively realize the substitution of electricity for coal, improve the energy structure of China's industrial sector and reduce carbon emissions.

About the substitution between coal and electricity, it can be seen that the oil self-price elasticity of most industries is high, greater than 0.5, indicating that the oil demand is greatly affected by the price. However, the oil price in China fluctuates with the international oil price, so the Chinese government cannot control the oil price completely. Then, in the substitution effect of coal to oil, the substitution results are generally low. Among the substitution effects of oil and coal, there are 8 industries that exceed the overall industrial level of 0.285, which are: cultural, educational and sporting goods manufacturing industry, ferrous metal mining and processing industry, ferrous metal smelting and rolling processing industry, and nonferrous metal smelting and rolling processing industry. It is effective to promote the substitution of oil for coal in these industries. Therefore, in cultural, educational and sporting goods manufacturing industry, ferrous metal mining and processing industry and other industries, oil can be used to replace coal, and compared with coal, oil has a lower carbon emission, so for such industries, oil can be promoted to replace coal and effectively improve the energy structure. But we must take into account that the oil price is affected by the international oil price, and China's oil reserves are obviously insufficient, so using oil to replace coal is not a long-term solution, we still need to seek other energy sources to replace coal. In view of the current situation of clean and low-carbon energy development, renewable energy will become a popular source of energy consumption. Therefore, the future development direction of China's energy substitution is to vigorously promote renewable energy.

Through the estimation of the substitution effect of petroleum and electric power, it is found that petroleum and electric power have a strong substitution relationship. The substitution elasticity of 15 industries is greater than 0.4, among which the metal products industry, non-ferrous metal mining and processing industry, agricultural and sideline food processing industry is more than 0.5. These industries are less dependent on petroleum. In the substitution elasticity of electric power and oil, the substitution elasticity of chemical fiber manufacturing, plastic and rubber manufacturing and general equipment manufacturing is 0.285 larger than the overall industrial substitution elasticity. However, it is also difficult to regulate the oil price, so it is impossible to effectively substitute oil with electricity. Therefore, the only way to save part of oil consumption is to adjust the price of electric power and adopt the strategy of replacing oil with electric power in the industries where the substitution effect of electric power to oil is greater.

4. Conclusion

From the result of energy substitution elasticity of Chinese industry, the internal substitution of energy is feasible. Therefore, in order to ensure the realization of China's established energy

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development goals as soon as possible, we need to accelerate the deepening of energy system reform in accordance with the future direction of energy substitution, and promote the implementation of energy conservation and emission reduction policies such as carbon tax and carbon trading. For example, for industries with high elasticity of coal and electricity substitution, lower electricity price should be adopted to reduce coal consumption. For the industries with high elasticity of coal and oil substitution, moderately subsidizing oil consumption can effectively reduce coal consumption. At the same time, China also needs to encourage the industrial sector to use clean energy instead of high-emission fossil energy, increase investment in research and development of renewable energy, implement carbon tax, carbon trading and other market emission reduction measures to improve China's energy consumption structure and improve energy use efficiency.

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