Analysis of Factors Affecting Energy Consumption Based on PDA Decomposition Method

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Abstract. In order to explore the influencing factors of regional energy consumption and guide energy conservation policy, this paper analyses the difference of energy consumption from the perspective of technology and efficiency. Based on the PDA decomposition framework, the Shephard distance function and the Malmquist index are introduced to decompose energy consumption changes into five parts and build a comprehensive decomposition model of energy consumption. The model considers several factors that affect the changes in energy consumption, and then analyses the changes in China's energy consumption from 2007 to 2013. The results are as follows: Potential energy intensity and potential capital output are the two main factors that affect China's energy consumption; among the factors driving the growth of energy consumption, the impact of potential per capita capital far exceeds the population change; technological progress and technical efficiency show more obvious regional characteristics, among which the former shows positive energy conservation mainly in the eastern region, while the latter shows significant suppression effect on energy consumption in the western region.

1. Introduction
China's economic development has a great dependence on energy and the expansion of economic aggregate will lead to an increase in energy demand [1]. However, renewable energy is not yet widely available, and fossil energy, which accounts for the vast majority of energy consumption, is a non-renewable energy source with limited global reserves. It can be seen that with the continuous economic development and increasing energy demand in China, the energy shortage and contradiction will become serious obstacles restricting China's economic and social development. Therefore, in-depth research on the main factors of China's energy consumption has important practical significance for handling the relationship between energy consumption, economic growth and the environment and achieving sustainable development of economic society, energy and environment [2]. In recent years, many scholars have carried out a lot of research on the factors affecting China's energy consumption, which can be roughly divided into exponential decomposition method [3,4], structural decomposition method [5] and econometric method [6,7]. The above research methods have certain defects in data collection or processing of results, especially the econometric model is subjective to the selection of variables. The
production theory decomposition model (PDA) proposed by Zhou and Ang [8] can not only effectively solve the problems caused by factor decomposition method and measurement method, but also can comprehensively examine the degree of influence of factors. So this paper introduces PDA model to analyze the driving factors of China's energy consumption growth, which can provide decision makers with more decision support.

2. PDA Decomposition model

The establishment of the PDA decomposition model needs to clarify the technology and relative efficiency, which is evaluated by the introduced Shephard distance function. First, define a production technology set \( \{ S^i(l^i, k^i, e^i, y^i) \} \), where \( l^i, k^i, e^i, y^i \) represents labor input, capital investment, energy input and total output. And define the energy distance function, the output distance function and the capital distance function respectively:

\[
\begin{align*}
D_e^\gamma &= \sup \{ \lambda : (l^i, k^i, e^i, y^i) \in \eta_i \}, \\
D_y^\gamma &= \sup \{ \delta : (l^i, k^i, e^i, y^i / \delta) \in \eta_i \}, \\
D_k^\gamma &= \inf \{ \varphi : (l^i, k^i / \varphi, e^i, y^i) \in \eta_i \}.
\end{align*}
\]

Then, the energy consumption change in the \([0, T]\) period can be decomposed into:

\[
H_e^\gamma = \frac{[e^T / D_e^0(S^T)] \times (1 / y^T) \times [y^T / D_y^0(S^T)] \times (1 / k^T) \times [k^T / D_k^0(S^T)] \times (1 / p^T) \times (p^T / p^0)}{[e^0 / D_e^0(S^0)] \times (1 / y^0) \times [y^0 / D_y^0(S^0)] \times (1 / k^0) \times [k^0 / D_k^0(S^0)] \times (1 / p^0) \times (p^T / p^0)}
\] (1)

The factor utilization performance index can be further divided as follows:

\[
U^0 = \frac{D_e^0(S^T)}{D_e^0(S^0)} \times \frac{D_y^0(S^T)}{D_y^0(S^0)} \times \frac{D_k^0(S^T)}{D_k^0(S^0)} = U_e^0 \times U_y^0 \times U_k^0
\] (2)

\[
U^T = U_e^T \times U_y^T \times U_k^T
\] (3)

Where \( P_e \) is potential energy intensity, \( P_y \) is potential capital output, \( P_p \) is potential per capita capital, \( H_p \) is population change, \( U \) is factor utilization performance index, \( U_e \) is energy utilization performance index, \( U_k \) is capital utilization performance index, \( U_y \) is output utilization performance index.

The geometric mean of equations (2) and (3) can be obtained:

\[
U = \frac{[D_e^0(S^T) \times D_y^0(S^T)]^{1/2} \times [D_y^0(S^T) \times D_k^0(S^T)]^{1/2} \times [D_k^0(S^T) \times D_e^0(S^T)]^{1/2}}{D_e^0(S^0) \times D_k^0(S^0) \times D_y^0(S^0)} = U_e \times U_y \times U_k
\] (4)

The three factors utilization performance index can be decomposed into the technical efficiency index and the technological progress index. Taking the energy utilization performance index as an example, the decomposition formula is as follows:

\[
U_e = \frac{D_e^T(S^T)}{D_e^0(S^0)} \times [\frac{D_y^0(S^T) \times D_k^0(S^T)}{D_y^0(S^T) \times D_k^0(S^0)}]^{1/2} = U_{e1} \times U_{e2}
\] (5)
Finally, taking the geometric mean of production techniques of 0 and T periods as a reference, the comprehensive decomposition model can be obtained as follows:

\[
H_e = (P_e^0P_e^T)^{1/2}(P_y^0P_y^T)^{1/2}(P_p^0P_p^T)^{1/2}(H_p^0H_p^T)^{1/2}(U_e^0U_e^T)^{1/2} = P_eP_yP_pH_pU_eU_yU_pH_yU_y
\]

(6)

3. Empirical analysis

30 provinces in China were selected and the trend of energy consumption and the decomposition of influencing factors in various provinces in China from 2007 to 2013 are obtained, as shown in Table 1.

Table 1. China's provincial energy consumption changes and index decomposition

| Provinces  | E    | P_e | P_y | P_p | H_p | U    |
|------------|------|-----|-----|-----|-----|------|
| Tianjin    | 1.8240 | 0.7691 | 0.7204 | 2.2581 | 1.4267 | 1.0218 |
| Liaoning   | 1.5698 | 0.8569 | 0.7223 | 2.8280 | 1.1390 | 0.7874 |
| Shanghai   | 1.2801 | 0.7314 | 0.9220 | 1.3844 | 1.2597 | 1.0884 |
| Fujian     | 1.6381 | 0.8066 | 0.7472 | 2.1242 | 1.3177 | 0.9711 |
| Guangdong  | 1.4593 | 0.8281 | 0.7699 | 2.1301 | 1.1524 | 0.9572 |
| Shandong   | 1.4537 | 0.5775 | 0.6303 | 1.6658 | 1.0997 | 2.1799 |
| Anhui      | 1.6067 | 0.8012 | 0.8244 | 2.3789 | 1.1245 | 0.9094 |
| Beijing    | 1.2158 | 0.4720 | 0.7034 | 1.0186 | 1.2040 | 2.9862 |
| Jiangsu    | 1.5152 | 0.5173 | 0.5880 | 1.4889 | 1.0282 | 3.2539 |
| Fujian     | 1.3674 | 0.6178 | 0.7560 | 1.3808 | 1.1636 | 1.8224 |
| Jilin      | 1.5983 | 0.5454 | 0.4661 | 2.6194 | 1.0843 | 2.2139 |
| Heilongjiang| 1.4612 | 0.6038 | 0.6142 | 1.8311 | 1.1366 | 1.8930 |
| Jiangsu    | 1.5521 | 0.5659 | 0.6428 | 1.7485 | 1.1212 | 2.1742 |
| Henan      | 1.4568 | 0.6348 | 0.5237 | 2.5977 | 1.0996 | 1.5342 |
| Hubei      | 1.5997 | 0.6191 | 0.6959 | 2.0561 | 1.0345 | 1.7457 |
| Hunan      | 1.5825 | 0.6442 | 0.7560 | 2.2980 | 1.0461 | 1.5068 |
| Sichuan    | 1.5844 | 0.5627 | 0.7559 | 1.5980 | 1.0177 | 2.2906 |
| Chongqing  | 1.7284 | 0.5373 | 0.8207 | 1.3600 | 1.1226 | 2.5673 |
| Guizhou    | 1.6005 | 0.6499 | 0.7118 | 2.1481 | 0.9348 | 1.7228 |
| Hebei      | 1.3880 | 0.6091 | 0.5813 | 1.7485 | 1.1318 | 1.9809 |
| Hainan     | 1.8348 | 0.9203 | 0.7851 | 1.9380 | 1.2654 | 1.0354 |
| Shanxi     | 1.3715 | 0.5660 | 0.4927 | 1.6199 | 1.1467 | 2.6478 |
| Yunnan     | 1.5759 | 0.7570 | 0.7357 | 2.4255 | 1.1447 | 1.0192 |
| Shaanxi    | 1.7337 | 0.6120 | 0.5997 | 2.3418 | 1.0378 | 1.9437 |
| Gansu      | 1.4773 | 0.6377 | 0.6522 | 2.0214 | 1.0644 | 1.6509 |
| Qingshui   | 1.8516 | 0.6860 | 0.5388 | 1.9399 | 1.0568 | 2.4438 |
| Ningxia    | 1.6120 | 0.6070 | 0.4742 | 1.7674 | 1.1181 | 2.8341 |
| Xinjiang   | 1.9564 | 0.9147 | 0.7175 | 1.3027 | 1.2448 | 1.8385 |
| Guangxi    | 1.6985 | 0.7934 | 0.5283 | 4.0471 | 1.0029 | 0.9984 |
| Neimeng    | 1.7633 | 0.5255 | 0.4288 | 2.0807 | 1.2413 | 3.0300 |
| Average    | 1.5722 | 0.6705 | 0.6689 | 2.0036 | 1.1278 | 1.8350 |

According to the report, China's average energy consumption increased by 57.22% from 2007 to 2013, and the provinces with faster energy consumption growth are located in the economically developed eastern regions, or the western regions where energy or mines are produced. The decomposition factors also showed some differences in different regions, as shown in Figure 1.

The change in potential energy intensity and potential capital expenditure are both less than 1, which means they inhibit the growth of energy consumption. Overall, China's energy consumption has decreased by 32.95% and 33.11%, which indicates that China's energy intensity decline and capital increase have reduced energy growth. At the regional level, the potential energy intensity has the greatest inhibitory effect on Beijing, and the least inhibitory effect on Hainan. The potential capital output has
the greatest energy-saving effect on Jilin, Inner Mongolia and Ningxia, and has the least energy-saving effect on Chongqing, Anhui and Shanghai.

The change in potential per capita capital and population are both greater than 1, which means they have contributed to the growth of energy consumption. It shows that in recent years, China’s per capita capital has increased significantly, and people’s living standards have been continuously improved, which has greatly promoted the growth of energy consumption. From a regional perspective, the potential per capita capital has less promotion effect on the six regions of Beijing, Xinjiang, Chongqing, Zhejiang, Shanghai and Jiangsu, and has the greatest promotion effect on Guangxi. This regional characteristic is consistent with the change law of per capita capital in each region. The growth rate of 14 regions such as Tianjin, Fujian and Shanghai is larger than the national average, which due to the high population concentration in the eastern region and the rapid urbanization process.

Figure 1. The influence of various factors on energy consumption in different regions

Then, the different effects of technological progress and technical efficiency on energy consumption in various provinces of China are analyzed. The results are shown in Table 2.

It can be seen that the average value of several factors utilizing technological progress and technical efficiency are greater than 1, indicating that China’s overall factor utilization technology progress level and technical efficiency are not very high, and can not play an energy-saving role. At the regional level, various factors’ influence on the energy consumption of 30 provinces in China has some regional differences. The technical efficiency index($U_{1y}$) and technical progress index($U_{2y}$) of output utilization are both greater than 1, indicating that the technical level development and technical efficiency improvement degree of output utilization in various regions are relatively low and don’t have a good inhibiting effect on energy consumption. In terms of energy utilization and capital utilization, the technical progress and technical efficiency index are obviously different in different regions, which leads to different influences on the energy consumption. In this paper, the effects of various factors on the growth in energy consumption are combined into six categories.

Type 1 includes Hebei, Hainan and other 10 provinces. These provincial $U_{e1}$ and $U_{k1}$ are less than 1 while $U_{e2}$ and $U_{k2}$ are greater than 1, but the final energy consumption index is greater than 1, which indicates that the improvement of technological efficiency in factors utilization can effectively reduce energy consumption in these regions but there is no technological progress of factors utilization in these regions. As a result, the energy saving effect cannot be shown eventually. Type 2 includes Guangxi province. Its provincial $U_{e1}$ and $U_{k1}$ are less than 1 while $U_{e2}$ and $U_{k2}$ are greater than 1, but the final energy consumption index is less than 1, which indicates that although there is no technological progress in factors utilization, significant improvement in technical efficiency of energy utilization and capital utilization has make energy saving effect. Type 3 includes Tianjin and Shandong. Both of their provincial $U_{e1}$ and $U_{k1}$ are greater than 1 while $U_{e2}$ and $U_{k2}$ are less than 1, but the energy consumption index is greater than 1. The technical efficiency of factors utilization has not been significantly improved and it cannot show positive energy saving effect. Type 4 includes Liaoning,
Fujian, Guangdong and Anhui. These provincial \( U_{e1} \) and \( U_{k1} \) are greater than 1 while \( U_{e2} \) and \( U_{k2} \) are less than 1, but the energy consumption index is less than 1, which indicates that there are significant technological advances in energy and capital utilization in these regions. As a result, the energy saving effect can be shown. Type 5 includes 12 provinces such as Beijing, Jiangsu and Zhejiang. All of these provincial changes in technological progress and technical efficiency are greater than 1. It indicates that there is neither technological progress nor improvement of factors utilization efficiency in these regions. Type 6 includes Shanghai. The changes of technical progress and technical efficiency are less than 1 but the energy consumption index is greater than 1, which indicates that although the technological progress and efficiency in the utilization of energy and capital have been greatly improved, the energy saving effect cannot be shown in the end due to the negative effect of technological progress and efficiency of output utilization.

Table 2. Factor utilization performance changes and indicator decomposition

| Provinces      | \( U \) | \( U_{e1} \) | \( U_{k1} \) | \( U_{y1} \) | \( U_{e2} \) | \( U_{k2} \) | \( U_{y2} \) |
|----------------|--------|--------------|--------------|--------------|--------------|--------------|--------------|
| Tianjin        | 1.0218 | 1.0120       | 1.0213       | 1.0475       | 0.9613       | 0.9360       | 1.0489       |
| Liaoning       | 0.7874 | 1.0487       | 1.0455       | 1.0824       | 0.8441       | 0.7850       | 1.0012       |
| Shanghai       | 1.0884 | 0.9570       | 0.9445       | 1.1064       | 0.9976       | 0.9809       | 1.1123       |
| Fujian         | 0.9711 | 1.0355       | 1.0366       | 1.0216       | 0.9415       | 0.9328       | 1.0084       |
| Guangdong      | 0.9572 | 1.0514       | 1.0811       | 1.0326       | 0.9051       | 0.8651       | 1.0416       |
| Shandong       | 2.1799 | 1.2854       | 1.3191       | 1.0614       | 0.9984       | 0.9837       | 1.2333       |
| Anhui          | 0.9094 | 1.0216       | 1.0275       | 1.0098       | 0.9267       | 0.9202       | 1.0060       |
| Beijing        | 2.9862 | 1.0685       | 1.0396       | 1.0685       | 1.3637       | 1.3530       | 1.3637       |
| Jiangsu        | 3.2539 | 1.1087       | 1.1235       | 1.1087       | 1.3177       | 1.3484       | 1.3261       |
| Zhejiang       | 1.8224 | 1.0639       | 1.0524       | 1.0524       | 1.1481       | 1.1589       | 1.1625       |
| Jilin          | 2.2139 | 1.0355       | 1.0254       | 1.0254       | 1.2754       | 1.2561       | 1.2693       |
| Heilongjiang   | 1.8930 | 1.0169       | 1.0215       | 1.0152       | 1.2254       | 1.1935       | 1.2275       |
| Jiangsu        | 2.1742 | 1.0476       | 1.0843       | 1.0476       | 1.2690       | 1.1347       | 1.2690       |
| Henan          | 1.5342 | 1.0149       | 1.0236       | 1.0149       | 1.1442       | 1.1115       | 1.1442       |
| Hubei          | 1.7457 | 1.1023       | 1.1023       | 1.1023       | 1.0928       | 1.0916       | 1.0928       |
| Hunan          | 1.5068 | 1.0533       | 1.0533       | 1.0533       | 1.0885       | 1.0885       | 1.0885       |
| Sichuan        | 2.2906 | 1.1293       | 1.1251       | 1.1293       | 1.1684       | 1.1692       | 1.1684       |
| Chongqing      | 2.5673 | 1.2299       | 1.2299       | 1.2299       | 1.1126       | 1.1147       | 1.1126       |
| Guizhou        | 1.7228 | 1.0701       | 1.0700       | 1.0701       | 1.1188       | 1.1233       | 1.1188       |
| Hebei          | 1.9809 | 0.9892       | 0.9973       | 1.0887       | 1.2319       | 1.2663       | 1.1823       |
| Hainan         | 1.0354 | 0.9764       | 0.9662       | 1.0214       | 1.0231       | 1.0198       | 1.0299       |
| Shanxi         | 2.6478 | 0.9413       | 0.9068       | 1.0168       | 1.3706       | 1.4883       | 1.4956       |
| Yunnan         | 1.0192 | 0.9984       | 0.8655       | 1.0127       | 1.0324       | 1.0122       | 1.1145       |
| Shaanxi        | 1.9437 | 0.9963       | 0.9878       | 1.0234       | 1.2820       | 1.2061       | 1.2481       |
| Gansu          | 1.6509 | 0.9964       | 0.9778       | 1.0316       | 1.2033       | 1.1745       | 1.1623       |
| Qinghai        | 2.4438 | 0.9956       | 0.9976       | 1.0452       | 1.3216       | 1.3129       | 1.3568       |
| Ningxia        | 2.8341 | 0.9639       | 0.9815       | 1.1376       | 1.3726       | 1.4986       | 1.2803       |
| Xinjiang       | 1.8385 | 0.9024       | 0.8931       | 1.0487       | 1.2690       | 1.4669       | 1.1686       |
| Guangxi        | 0.9984 | 0.9443       | 0.9307       | 1.0096       | 1.0741       | 1.0427       | 1.0047       |
| Neimeng        | 3.0300 | 0.9992       | 0.9874       | 1.1598       | 1.3933       | 1.4819       | 1.2825       |
| Average        | 1.8350 | 1.0352       | 1.0306       | 1.0625       | 1.1491       | 1.1506       | 1.1707       |
Figure 2. Regional differences in the impact of technological progress and technological efficiency

The reason for this phenomenon is the geographical difference of our country. During the 11 regions in type 1 and type 2, 8 provinces are from the western region. In recent years, due to the increasing support from the state in the western region, the technical efficiency of factors utilization in the western region has played a good role in energy conservation. All the regions in type 3 and type 4, except Anhui, are located in the economically developed east area. Their utilization technology level are relatively high, while there is little room for improvement in the technical efficiency of factors utilization, which makes it impossible to effectively save energy. The level of technological progress and the improvement degree of technical efficiency of type 5 show no energy saving effect. Type 6 (Shanghai) belongs to the municipality directly under the central government with highly developed economy, but the capital utilization technology still needs to be further improved.

4. Conclusion
In this paper, Shephard distance function and Malmquist index are introduced. Under PDA analysis framework, factors of energy consumption are decomposed into five aspects and the impact of technological progress and technical efficiency is investigated. The main conclusions are as follows:
(1) The decrease of potential energy intensity and the increase of potential capital output restrain the growth of energy consumption well. (2) Potential per capita capital and population change are the two main factors driving the growth of energy consumption in China. And the improvement of people's living standard has a far greater impact on energy conservation than the increase in the number of people. (3) There are obvious regional differences in technological progress and efficiency. Technological progress has a negative impact on the energy saving effect of most eastern regions, while technological efficiency shows the energy saving effect in many western regions.

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References
[1] Xiao Tao, Zhang Zongyi, Wang Feng. The relationship between regional energy consumption and economic growth in China—an empirical analysis based on panel data of energy input provinces and export provinces[J]. Management engineering Newspaper, 2012(3): 74-79.
[2] Fang Guochang, Tian Lixin, et al. The impact of new energy development on energy intensity
and economic growth[J]. Systems Engineering Theory and Practice, 2013(11): 2795-2803.

[3] Yue Ting, Long Ruyin. Spatial Econometric Analysis of China's Provincial Living Energy Carbon Emissions[J]. Journal of Beijing Institute of Technology, 2014(2): 40-46.

[4] Zhou Guofu, Zhao Huiqing. Analysis of Factors Affecting Energy Consumption—Based on Industry Decomposition and Regional Decomposition Method[J]. Industrial Economics Research, 2012(10): 87-94.

[5] Zhu Q, Peng X Z, Wu K Y. Calculation and Decomposition of Indirect Carbon Emissions from Residential Consumption in China Based on the Input-output Model[J]. Energy policy, 2012(48): 618-626.

[6] Dong Feng, Tan Qingmei, et al. The impact of technological progress, industrial structure and degree of openness on China's energy consumption—based on the gray correlation analysis-co-integration test two-step method empirical[J]. China Population Resources and Environment, 2010(6): 22-27.

[7] Wu Yuming. Determinants and spatial spillover effects of regional energy consumption in China—an empirical study based on spatial panel data econometric model[J]. Journal of Nanjing Agricultural University, 2012(10): 124-132.

[8] Zhou P, Ang B W. Decomposition of Aggregate CO2 Emissions: A Production—theoretical Approach[J]. Energy Economics, 2008(3): 1054-1067.