Dynamic relationship between energy structure and economic development under the background of global energy Internet

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Abstract. With the continuous development of global energy internet, the energy structure is constantly optimized, economic growth and total energy consumption are gradually decoupled, and the optimization of energy structure will gradually become one of the key factors for economic development. For this reason, this paper studies the dynamic relationship between energy structure and economic development under the background of global energy internet. Firstly, based on Panel Data Model and production function, the dynamic relationship model of energy structure and economic development is constructed; secondly, the economic growth and various energy consumption data of 30 provinces in China from 2010 to 2016 are selected for empirical analysis to quantitatively evaluate the role of various energy sources in promoting economic growth; finally, the relationship between energy structure and economic development is clarified through elasticity theory. This paper analyses the economic benefits of energy structure optimization under the background of global energy Internet.

1. Introduction
With the increasing prominence of energy and environmental problems all over the world, energy issues have become the constraints of economic development. At the stage of industrialization and urbanization, the growth rate of energy consumption is often regarded as an important indicator to judge the economic situation [1]. However, with the progress of science and technology and the improvement of energy efficiency, the industrial structure and energy structure are constantly changing, and economic growth and energy consumption are gradually decoupled. Under the new normal economic development, there is no obvious correlation between economic growth and energy consumption. We can not simply take the growth rate of energy consumption as the reference of economic growth. The optimization of energy structure will gradually become one of the key factors for economic development [2].

The adjustment of energy structure is an important way to solve the constraints of resources and environment, improve the security level of energy supply and achieve sustainable development [3]. Under the background of energy internet, energy market and energy network structure are developing towards decentralization [4]. Clean substitution and electric energy substitution are the inevitable trend of future energy development. This means that the global energy structure is adjusting to the direction of low carbon and environmental protection [5]. The main manifestation is that the proportion of fossil energy is gradually decreasing and natural gas will be taken. Instead of coal, it has become the second largest fuel in fossil energy, and renewable energy has gradually become the world’s leading energy. In
primary energy consumption, hydropower, nuclear power and renewable energy power generation have become the world’s leading energy [6]. Therefore, under the background of global energy internet, it is very important to explore the dynamic relationship between energy structure and economic growth, and to analyze the economic benefits of energy structure change [7].

Therefore, based on Panel Data Model and production function, this paper constructs a dynamic relationship model between energy structure and economic development. The total production value, employment population, fixed capital stock, petroleum consumption, coal consumption, natural gas consumption and primary electricity consumption including hydropower, nuclear power and various renewable energy generation in 30 provinces of China from 2010 to 2016 are selected. According to this, we quantitatively analyze the promoting effect of different types of energy consumption growth on economic development, so as to clarify the dynamic relationship between energy structure and economic growth, and then explore the economic benefits of energy structure change in the process of global energy Internet development.

2. Dynamic Relation Model of Energy Structure and Economic Development Based on Panel Data

2.1. Panel Data Model
Panel data model belongs to econometrics and is the aggregation of horizontal data and vertical data. It has both horizontal data of multiple individuals and hierarchical data across different time dimensions (usually representing individual differences horizontally and time vertically). Lateral data can be used to make up for the problems of obvious trend, small amount of data and correlation of vertical data. It has natural advantages in the study of the relationship between energy structure and economic growth. Panel data models are mainly divided into three categories: mixed regression model, fixed effect model and random effect model.

The steps for building a panel data model are shown in Figure 1.

![Flow chart of panel data model construction.](image)

2.2. Dynamic relationship model between energy structure and economic development based on Panel Data
The production function shows the relationship between the use of various input factors in each period and the maximum quantity of a commodity that can be produced by using these inputs. The general form of production function is as follows:

\[ Y = F(X_1, X_2, \ldots, X_n) \]  

Among them, \( Y \) is output and \( X_1 \sim X_n \) are all kinds of production factors.
There are many ways to express the production function. This paper uses Cobb-Douglas production function (hereinafter referred to as C-D production function). The Cobb-Douglas production function was proposed by the mathematician C.W. Cobb and the economist Paul H. Douglas in the 1930s. Cobb-Douglas production function is considered to be a very useful production function, because it has some properties that economists care about in its simple form, and it has certain significance in the analysis and application of economic theory.

The general form of C-D production function is as follows:

\[ Y = AK^\alpha L^{1-\alpha}/(0 < \alpha < 1) \]  

Among them, \( Y \) represents output, \( K \) represents capital input, \( L \) represents labor input and \( A \) represents technological progress. \( 1-\alpha \) and \( \alpha \) are the output elasticity of capital and labor.

In order to further study the relationship between energy and economic growth, it is assumed that all kinds of energy input have the same impact on economic growth as capital input and labor input. Several main energy sources are included in the production function.

For the selection of indicators, this paper comprehensively considers four categories and seven indicators, namely, total economic indicators, capital indicators, labor (human resources) indicators and various energy consumption indicators. Energy indicators include oil, coal, natural gas and primary power generation including hydropower, nuclear power and various renewable energy sources. The selection of each index is as follows:

| Variable name                  | Representation method | variable | Company          |
|--------------------------------|-----------------------|----------|------------------|
| Interpreted variables          |                       |          |                  |
| Gross Domestic Product         |                       | Y        | Billion yuan     |
| control variable               |                       |          |                  |
| Number of Employed Persons     |                       | K        | ten thousand people |
| Fixed capital stock            |                       | L        | Billion yuan     |
| Oil consumption                |                       | Oil      | Ten thousand tons of standard coal |
| Coal consumption               |                       | Coal     | Ten thousand tons of standard coal  |
| Natural gas consumption        |                       | Gas      | Ten thousand tons of standard coal  |
| Primary electricity consumption|                       | Ele      | Ten thousand tons of standard coal  |

Combining the characteristics of C-D function and the purpose of studying the relationship between energy structure and economic growth, i.e. explaining the impact of variable input changes on the explained variables, this paper takes logarithms on both sides of the model, and finally gets the following model:

\[ \ln Y = \alpha_1 \ln K + \alpha_2 \ln L + \alpha_3 \ln Oil + \alpha_4 \ln Coal + \alpha_5 \ln Gas + \alpha_6 \ln Ele + C \]  

3. Empirical analysis

3.1. Basic data
Because some data of Tibet, Hong Kong, Macao and Taiwan are not published officially and can not be obtained, this paper selected 30 regions (excluding Tibet, Hong Kong, Macao and Taiwan) in China from 2010 to 2016. The variables of the study are the gross domestic product, energy consumption (including Coal, Oil, Natural Gas and Primary Electricity), employment population \( K \) and fixed capital stock of each region in each year \( L \). In order to make the data be processed logarithmically, the obtained data are shown in Figure 2-5.
Figure 2. ln $Y$ data map of 30 provinces, 2010-2016

Figure 3. ln $K$ and ln $L$ data maps of 30 provinces, 2010-2016.

Figure 4. ln $Oil$ and ln $Gas$ data map of 30 provinces, 2010-2016.

Figure 5. ln $Gas$ and ln $Ele$ data map of 30 provinces, 2010-2016.
3.2. **Unit root test and cointegration test**

The results of data stationarity test are as follows:

| Variable   | LLC    | IPS  | Fisher-ADF | Fisher-PP | conclusion  |
|------------|--------|------|-------------|-----------|-------------|
| LNY        | 0.0000 | 0.1934 | 0.0431      | 0.0000    | Non-stationary |
| D(LNY)     | 0.0000 | 0.0000 | 0.0000      | 0.0000    | Stationary   |
| LNK        | 0.0000 | 0.2330 | 0.0572      | 0.0000    | Non-stationary |
| D(LNK)     | 0.0000 | 0.0700 | 0.0280      | 0.0001    | Stationary   |
| LNL        | 0.0000 | 0.3150 | 0.1013      | 0.0000    | Non-stationary |
| D(LNL)     | 0.0000 | 0.0000 | 0.0000      | 0.0000    | Stationary   |
| LNOIL      | 0.0000 | 0.8021 | 0.7040      | 0.0168    | Non-stationary |
| D(LNOIL)   | 0.0000 | 0.0000 | 0.0000      | 0.0000    | Stationary   |
| LNCOAL     | 0.0000 | 0.5024 | 0.3047      | 0.0000    | Non-stationary |
| D(LNCOAL)  | 0.0000 | 0.0000 | 0.0000      | 0.0000    | Stationary   |
| LNGAS      | 0.0000 | 0.1169 | 0.0044      | 0.0000    | Non-stationary |
| D(LNGAS)   | 0.0000 | 0.0110 | 0.0043      | 0.0000    | Stationary   |
| LNELE      | 0.0000 | 0.6405 | 0.5390      | 0.0002    | Non-stationary |
| D(LNELE)   | 0.0000 | 0.0000 | 0.0000      | 0.0000    | Stationary   |

According to the test results, GDP, employment, fixed assets investment, oil production, gas production, coal production and primary electricity consumption are all stable, and through co-integration test, the variables meet the same level of monolithic.

3.3. **Model selection**

1) **F test**

The likelihood ratio test results are shown in the table below, so the mixed model is rejected.

| Effects Test                  | Statistic         | d.f        | Prob  |
|-------------------------------|-------------------|------------|-------|
| Cross-section F               | 103.004403        | (29,174)   | 0.0000|
| Cross-section Chi-square      | 608.922050        | 29         | 0.0000|

2) **Hausman test**

Hausman test results are shown in the table below, rejecting the original hypothesis and finally choosing the fixed effect model.

| Test Summary       | Chi-Sq. Statistic | Chi-Sq. d.f. | Prob  |
|--------------------|-------------------|--------------|-------|
| Cross-section random | 26.468360         | 6            | 0.0002|
3.4. Fitting result
Fixed-effect model is used to estimate the data. The results are shown in the table below.

Table 5. Fixed Effect Model Estimation Result Table.

| Variable | Coefficient | Std. Error | t-Statistic | Prob. |
|----------|-------------|------------|-------------|-------|
| C        | 2.308274    | 0.857184   | 2.692857    | 0.0078|
| LNK?     | 0.257759    | 0.127883   | 2.015582    | 0.0454|
| LNL?     | 0.495732    | 0.024466   | 20.26172    | 0.0000|
| LNOIL?   | 0.008190    | 0.009328   | 0.877995    | 0.3812|
| LNGAS?   | 0.119742    | 0.025776   | 4.645569    | 0.0000|
| LNOIL?   | -0.013525   | 0.038134   | -0.354670   | 0.7233|
| LNELE?   | 0.018602    | 0.013388   | 1.389423    | 0.1665|

Therefore, the fitting results are as follows:

\[
\ln Y = 0.257759 \ln K + 0.495732 \ln L + 0.008190 \ln Oil + 0.119742 \ln Gas - 0.013525 \ln Coal + 0.018602 \ln Ele + 2.308274
\]  

(4)

Namely,

\[
Y = 2.308274K^{0.257759}L^{0.495732}Oil^{0.008190}Gas^{0.119742}Coal^{-0.013525}Ele^{0.018602}
\]  

(5)

According to the results, GDP is positively correlated with oil, natural gas and primary electricity consumption, and negatively correlated with coal consumption. Generally speaking, energy is an important driving factor for economic development, but increasing coal consumption will restrict economic development. Therefore, it is urgent to reduce coal consumption and promote the transformation of energy structure from coal-based to diversified.

3.5. Economic Benefit Analysis of Energy Structure Adjustment under the Background of Global Energy Internet

Elasticity refers to the degree of variation of dependent variables caused by the change of independent variables. For function \(y = f(x)\), the elastic formula is:

\[
\frac{\Delta y}{y} = \frac{\frac{dy}{dx}}{f(x)} = \frac{dy}{dx} \frac{x}{y}
\]  

(6)

According to formula (5) and (6), the elastic coefficients of economic development for each explanatory variable are calculated, and the results are shown in the table below.

Table 6. Elastic calculation results table.

| Explanatory variable | Oil  | Gas  | Coal | Ele  |
|----------------------|------|------|------|------|
| Elasticity coefficient| 0.008190 | 0.119742 | -0.013525 | 0.018602 |

According to the calculation results, the elasticity coefficient of GDP to natural gas is 0.119742, and the growth of natural gas consumption has the strongest effect on GDP growth. For every 10% increase in natural gas consumption and 1.20% increase in GDP, the elasticity coefficient of GDP to primary electricity consumption is 0.018602, followed by that of primary electricity consumption, and the elasticity coefficient of GDP to oil is 0.008190% and 0.19% for every 10% increase in primary electricity consumption. The effect of oil consumption growth on GDP growth is the weakest. For every 10% increase in oil consumption, GDP growth is 0.08%. The elasticity coefficient of GDP to coal...
consumption is -0.013525, that is, GDP is negatively correlated with coal consumption. Increasing coal consumption will restrict economic development.

With the development of the global energy internet, according to the forecast of China Energy Research Association, by 2030, the proportion of coal consumption in China will drop to 49%, 15 percentage points lower than that in 2015; the proportion of oil consumption will fall to 17%, with a small decrease; and the total proportion of clean energy power generation (including natural gas and non-fossil energy) will reach 34%, which is 16 percentage points higher than that in 2015. On the one hand, the proportion of coal consumption has declined dramatically, and the restraint to economic development has been reduced. On the other hand, the proportion of natural gas and primary electric power, which play a strong role in promoting GDP growth, has increased significantly. Only the proportion of oil consumption, which has the weakest role in promoting GDP growth, has declined slightly. Therefore, it is reasonable to believe that the adjustment of energy structure brought about by the construction and development of the global energy Internet has a greater impact.

4. Conclusion
This paper studies the dynamic relationship between energy structure and economic development under the background of global energy internet. The dynamic relationship model between energy structure and economic development is constructed, and the economic growth and energy consumption data of 30 provinces in China from 2010 to 2016 are selected for empirical analysis. The results show that natural gas consumption and primary electricity consumption are important driving factors for economic development, while oil consumption has no significant effect on economic development, and increasing coal consumption will restrict economic development. With the development of global energy internet, natural gas will replace coal as the second largest fuel in fossil energy in the future, and renewable energy will gradually become the world's leading energy, which will bring remarkable economic benefits.

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