Energy Rebound Effect Analysis Based on Technological Progress

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Abstract. China's energy consumption is facing the dual pressure of economic growth and environmental protection. The analysis of energy rebound effect is of great significance to China's energy efficiency improvement. Based on the LMDI decomposition method, the author established the model for rebound effect calculation and empirically analyzed the energy rebound effect in China from 1997 to 2017. The empirical results show that the improvement of energy efficiency caused by technological progress can save energy consumption, but the rebound effect of energy consumption exists significantly. The rebound effect of energy consumption in China ranged from 3.67% to 134.18%, with an average rebound effect of 34.85%. The impact of technological progress on energy efficiency is a dynamic process. The rebound effect fluctuates in different degrees in different periods.

Key words: rebound effect; technological progress; LMDI.

1. Introduction

With the rapid development of China's economy, the gap between energy supply and demand in China is widening year by year. The energy gap widened from 65 million tons in 2001 to 684 million tons in 2015. At the same time, coal as the main energy consumption has caused haze weather in many cities of China. In order to ease the contradiction between energy supply and demand and strengthen environmental protection, China has made great efforts to improve energy efficiency. China's energy intensity is declining. However, the improvement of energy efficiency saves energy consumption and increases energy demand at the same time. This makes the total energy consumption increase, and produces the energy rebound effect. Therefore, the analysis of energy rebound effect has important theoretical value and practical significance for China to improve energy efficiency and achieve sustainable development of energy resources.

In the 1860s, Stanley Jevons proposed "Jevon's paradox". Since then, the rebound effect of energy has attracted the attention of governments and academic circles all over the world. In order to explain "Jevon's paradox", later scholars proposed the concept of energy rebound effect. In 1992, Saunders confirmed the existence of energy rebound effect with the help of neoclassical economic growth theory. Subsequently, many scholars have deeply studied the mechanism of energy rebound effect and conducted empirical research. Simon Koesler et al. (2016) used CGE simulation model to study the international spillover and rebound effects of energy efficiency improvement in Germany. Tahar Abdessalem, Etidel Labidi (2016) used the general equilibrium method to explore the direct and indirect impact of energy rebound on family behavior. Manuel Llorca and Tooraj Jamasb (2017) used SFA to
estimate energy demand function to study the influence of key characteristics of rebound effect on road freight sector. Dirk Brounen. (2017) studied the rebound effect of residential heating by using instrumental variables and fixed-effect methods. Taoyuan Wei and Yang Liu (2017) adopted the CGE model to identify the global rebound effect, and the research results showed that the rebound effect of global energy use and related emissions was very large in 2040. Xiaoling Ouyang. (2018) used DOLS and SUR methods to estimate the rebound effect of YRDUA industrial sector. Xiaolei Wang. (2018) evaluated the rebound effect of China's steel industry from 1985 to 2015 based on the three-input trans-log cost function model. Golnaz Amjadi. (2018) used SFA to measure the four most energy-intensive parts of Sweden and found that neither fuel nor power rebound effects could completely offset the potential energy and emission savings.

Through the reviewing relevant literatures, it can be seen that the existing studies mainly focus on the degree of energy rebound effect. The research object mainly focuses on the aspects of household heating, automobile transportation and household electricity consumption. Scholars use different methods to measure the rebound effect of energy, and the research scope includes the macro national, regional and micro levels. Due to the differences in regional economic development level, production technology level, industrial structure and energy price, the rebound effect of energy consumption varies in different regions. Based on China's actual situation, this paper uses the theory of energy rebound effect to analyze the mechanism and effect of China's technological progress on energy consumption, and then puts forward countermeasures and suggestions for China to optimize energy consumption, promote economic transformation and upgrading, and achieve sustainable economic development.

2. Calculation Model of Energy Rebound Effect

2.1. The Mechanism of Energy Rebound Effect
Existing studies analyze the mechanism of energy rebound effect under the framework of neoclassical growth theory. The theory holds that economic growth depends on factor input and technological progress, among which technological progress is the decisive factor of long-term economic development. According to this theory, technological progress can improve energy efficiency, reduce energy unit consumption and bring new energy consumption at the same time. When technological progress leads to increased energy efficiency, energy consumption per unit of product decreases. Producers tend to use more energy instead of other input factors, while consumers tend to consume more energy. This results in some of the energy savings generated by increased energy efficiency being offset by additional energy consumption.

2.2. Decomposition of Energy Intensity
Scholars have studied the decomposition of factors affecting energy intensity, including Paasche decomposition method, Laspeyres exponential decomposition method, AMDI decomposition method and LMDI decomposition method. Among them, LMDI decomposes technological progress from factors affecting energy efficiency, and estimates the impact of technological progress on energy intensity. It overcomes the defects that most scholars attribute the factors affecting energy intensity, such as industrial structure adjustment and government regulation, to technological progress, making the calculation of energy rebound effect more accurate. LMDI decomposition method can better explain the change of energy intensity when studying the change of energy intensity, and is more consistent with the actual situation. It has been widely used in the analysis of the change of energy intensity. In this paper, the logarithmic mean Dirichlet decomposition (LMDI) method is used to decompose the factors of energy intensity change.

LMDI model is based on transformation operation of mathematical identities. Its basic idea is as follows:

\[
I_t = \frac{E_t}{Y_t} = \sum_i \frac{E_{i,t}}{Y_{i,t}} \frac{Y_{i,t}}{Y_t} = \sum_i I_{i,t} S_{i,t}
\]
Among them, $I_t$, $E_t$, $Y_t$ respectively represent actual energy intensity, energy consumption and actual total output. $I_{i,t}$, $E_{i,t}$, $Y_{i,t}$, $S_{i,t}$ represent the actual energy intensity, energy consumption, output level and the proportion of output of industry $I$ in phase $t$. Assuming that from the period 0 to the period $T$, the actual energy intensity changing from $I_0$ to $I_T$, the process can be expressed in the form of addition as follows:

$$
\Delta I_{tot} = I_T - I_0 = \Delta I_{tec} + \Delta I_{str} = \sum_i L(w_{i,t-1}, w_{i,t}) \ln \left( \frac{I_{i,t}}{I_{i,t-1}} \right) + \sum_i L(w_{i,t-1}, w_{i,t}) \ln \left( \frac{S_{i,t}}{S_{i,t-1}} \right)
$$

Where, the change of actual energy intensity can be divided into $\Delta I_{tec}$ and $\Delta I_{str}$. Among them, $\Delta I_{tec}$ represents technical effect and $\Delta I_{str}$ represents structural effect. $L(w_{i,t-1}, w_{i,t})$ is called logarithmic mean, $w_{i,t} = I_{i,t} \times S_{i,t}$. It has the following definitions:

$$
L(w_{i,t-1}, w_{i,t}) = \frac{w_{i,t} - w_{i,t-1}}{\ln \left( \frac{w_{i,t}}{w_{i,t-1}} \right)}
$$

The technical effect values can be constructed by using formula (2):

$$
\delta = \frac{\Delta I_{tec}}{\Delta I_{tot}}
$$

2.3. Measurement of Contribution Rate of Technological Progress

Under the framework of neoclassical growth theory, many scholars used different production functions to estimate the contribution rate of technological progress. Saunders(2008) systematically analyzed the applicability of various production functions to calculate the rebound effect, and believed that the Cobb-Douglas production function could better explain the rebound effect of energy in both theory and practice. The Cobb-Douglas production function has been widely used in the research of energy rebound effect. Solow residual method is widely used to calculate the contribution rate of technological progress to economic growth. According to the neoclassical economic growth theory, this paper constructs the Cobb-Douglas production function including capital $K$, labor $L$ and energy $E$.

$$
Y = A F(L, K, E) = AK^\alpha L^\beta E^\gamma
$$

Among them, $A$ represents technical level and $Y$ represents total output. $\alpha$, $\beta$ and $\gamma$ are the elasticity of output of capital, labor and energy respectively.

Take the logarithm of both sides of equation (5), and we can get

Assuming that $R_Y$, $R_K$, $R_L$ and $R_E$ are the growth rates of output, capital, labor and energy respectively, the contribution rate of technological progress can be expressed as:

$$
\rho = \frac{R_Y - \alpha R_K - \beta R_L - \gamma R_E}{R_Y} \times 100%
$$

2.4. Calculation of Energy Rebound Effect

By calculating the technical effect value, the energy saving amount caused by technological progress in year $t+1$ can be estimated.

$$
\Delta E_{t+1}^{save} = \delta \times Y_{t+1} \times (I_t - I_{t+1})
$$
Among them, \( \delta \) is the technical effect value mentioned above. It and \( Y_{t+1} \) are energy intensity in year \( t \) and year \( t+1 \) respectively. \( Y_{t+1} \) represents the total output in year \( t+1 \).

The new energy demand generated by economic growth driven by technological progress is:

\[
\Delta E_{\text{need}}^{t+1} = \rho \times I_{t+1} \times (Y_{t+1} - Y_t)
\]

Among them, \( \rho \) is the contribution rate of technological progress mentioned above. Therefore, the energy rebound effect generated by technological progress can be expressed as:

\[
RE = \frac{\Delta E_{\text{need}}^{t+1}}{\Delta E_{\text{save}}^{t+1}} = \frac{\rho \times I_{t+1} \times (Y_{t+1} - Y_t)}{\delta \times Y_{t+1} \times (I_t - I_{t+1})} \times 100\%
\]

When \( RE > 1 \), the improvement of energy efficiency not only does not reduce energy consumption but also increases it, and the energy-saving policy fails. When \( RE = 1 \), the energy saving amount brought by energy efficiency is just offset by the energy resilience, and the energy saving policy fails. When \( 0 < RE < 1 \), the energy saving brought about by the improvement of energy efficiency is partially offset by the rebound, which has positive energy saving effect. When \( RE \leq 0 \), the improvement of energy efficiency only leads to the reduction of energy consumption, which is in an ideal state.

3. The Empirical Analysis

3.1. Data Source and Processing

This paper analyzes the change trend of energy intensity in China from 1998 to 2017. The variables involved include total output \( Y \), capital input \( K \), labor input \( L \), and energy input \( E \). Total output \( Y \) is measured by GDP over the years, and adjusted by the consumer price index in the base period of 1978. Capital input \( K \) is calculated by means of the perpetual inventory method, that is \( K_t = I_t + (1 - \varphi_t)K_{t-1} \). \( \varphi_t \) is the depreciation rate of fixed assets. Labor input \( L \) is measured by the number of employees at the end of the year. Energy input \( E \) is measured by energy consumption. When the LMDI method decomposes the changing factors of energy intensity, the three industries are divided as follows: primary industries include agriculture, forestry, animal husbandry and fishery; Secondary industries include industry and construction; The tertiary industry includes transportation, warehousing, postal and other industries. The above data are from China Statistical Yearbook and China Energy Statistical Yearbook. Data is processed by Eviews 7.2.

3.2. Empirical Analysis of Energy Rebound Effect

Decomposing technological progress from factors affecting energy efficiency by LMDI method, the technical effect of energy intensity change in China from 1998 to 2017 is calculated as shown in the following table.

**Table 1.** The technical effect value of China from 1998 to 2017

| Year | Technical effect value | Year | Technical effect value | Year | Technical effect value | Year | Technical effect value |
|------|------------------------|------|------------------------|------|------------------------|------|------------------------|
| 1998 | 1.0772                 | 2003 | 0.7398                 | 2008 | 1.0166                 | 2013 | 0.9874                 |
| 1999 | 1.1087                 | 2004 | 0.8162                 | 2009 | 0.8103                 | 2014 | 0.9562                 |
| 2000 | 0.8965                 | 2005 | 0.9532                 | 2010 | 1.2639                 | 2015 | 0.9803                 |
| 2001 | 1.4137                 | 2006 | 0.9098                 | 2011 | 1.3883                 | 2016 | 0.9767                 |
| 2002 | 0.4706                 | 2007 | 0.9952                 | 2012 | 0.9974                 | 2017 | 0.9732                 |

Using Solow residual method, the contribution rate of technological progress in China from 1998 to 2017 is calculated as shown in the following table.
Table 2. The technology contribution rate of China from 1998 to 2017

| Year | Technology contribution rate | Year | Technology contribution rate | Year | Technology contribution rate | Year | Technology contribution rate |
|------|------------------------------|------|------------------------------|------|------------------------------|------|------------------------------|
| 1998 | 0.1818                       | 2003 | 0.1007                       | 2008 | 0.2176                       | 2013 | 0.2284                       |
| 1999 | 0.1644                       | 2004 | 0.0577                       | 2009 | 0.0714                       | 2014 | 0.1449                       |
| 2000 | 0.2482                       | 2005 | 0.1627                       | 2010 | 0.1697                       | 2015 | 0.1395                       |
| 2001 | 0.2174                       | 2006 | 0.2913                       | 2011 | 0.1209                       | 2016 | 0.1348                       |
| 2002 | 0.2115                       | 2007 | 0.3795                       | 2012 | 0.0505                       | 2017 | 0.1301                       |

According to the calculation model of energy rebound effect, the energy rebound effect of China from 1998 to 2017 is calculated as follows.

Table 3. The energy rebound effect of China from 1998 to 2017

| Year | Energy rebound effect | Year | Energy rebound effect | Year | Energy rebound effect | Year | Energy rebound effect |
|------|-----------------------|------|-----------------------|------|-----------------------|------|-----------------------|
| 1998 | 3.67%                 | 2003 | 11.64%                | 2008 | 27.02%                | 2013 | 34.42%                |
| 1999 | 17.77%                | 2004 | 134.18%               | 2009 | 18.24%                | 2014 | 20.45%                |
| 2000 | 29.71%                | 2005 | 108.64%               | 2010 | 19.02%                | 2015 | 16.40%                |
| 2001 | 33.54%                | 2006 | 63.45%                | 2011 | 13.77%                | 2016 | 16.06%                |
| 2002 | 52.87%                | 2007 | 50.90%                | 2012 | 8.66%                 | 2017 | 16.66%                |

4. Conclusions

Based on the LMDI decomposition method, this paper establishes the calculation model of energy rebound effect, and then calculates the energy rebound effect in China, and draws the following conclusions.

The improvement of energy efficiency caused by technological progress can save energy consumption, but the rebound effect of energy consumption exists significantly. The rebound effect of energy consumption in China ranged from 3.67% to 134.18%, with an average rebound effect of 34.85%. This shows that more than half of the energy saving amount brought by technological progress is offset by the energy resilience, and some energy saving effect is achieved, but there is still a large room for improvement.

The development trend of energy resilience effect in China from 1998 to 2017 can be divided into three stages: partial rebound effect stage(1998-2003), reverse effect stage(2004-2005) and partial rebound effect stage(2006-2017). The rebound effect in these three stages is 24.87%, 121.41% and 25.42% respectively. The fluctuation range is large, which may be caused by the instability of macroeconomic policy orientation.

In the LDMI decomposition of influencing factors of energy intensity, the technical effect values of 1998-2017 are all greater than 0.5, and even more than 1 in many years. This shows that the main factor of energy intensity change in China is technological progress, and the industrial structure has little impact on energy intensity change.

The continuous growth of China's total energy consumption, the intensification of the contradiction between supply and demand, and the unreasonable energy structure are all serious challenges facing China. The significance of energy rebound effect should be fully considered when improving energy efficiency through technological progress. Considering the rebound effect, China should give priority to promoting technological innovation, improving energy efficiency and adjusting industrial structure when formulating energy conservation policies. Although China's energy rebound effect has been reduced, there is still a lot of room for energy conservation.
Acknowledgments
2018 special scientific research project of Shaanxi province department of education “Research on the Way of Shaanxi Economic Growth from the Perspective of Supply-side Structure Reform” (18JK1060); School-level Scientific Research Foundation Projects in 2018 of Xi’an Eurasia University “Research on Shaanxi’s Economic Growth Path from the Perspective of Supply-side Structure Reform” (2018XJSK11).

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