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Viewpoint

Research on energy-saving effect of technological progress based on Cobb–Douglas production function

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ABSTRACT

Energy issues receive more and more attention these days. And it is considered that technological progress is an essential approach to save energy. This essay is to analyze the relation between energy intensity and technological progress by Cobb–Douglas production function in which energy, labor, capital and technological progress are taken as independent variables. It proves that the growth of output per capital and output per labor will increase energy intensity while technological progress will decrease energy intensity. Empirical research on Chinese industry is used here to indicate technological progress greatly decreases energy intensity. Because of the interferences of Asian financial crisis, there is something abnormal in the data. So in the empirical research, average weaken buffer operator (ABWO) is applied to weaken the interference of Asian financial crisis to the fixed assets, energy and value added. The results of the empirical research show that technological progress decreases energy intensity of Chinese industry an average of 6.3% every year in China.

1. Introduction

Energy consumption is so strongly related to economic growth that energy is one of the essential elements in modern economy. In terms of the economic growth of China, energy issue has become a core problem of its sustainable development. Since 2006, it has become an important aim of the government to decrease energy intensity. The energy-saving effect through adjusting industry structure is not obvious, and technological progress plays as the most effective method to reduce energy intensity.

Technological progress has an effect on energy consumption in different ways. On the one hand, technological progress will create lots of new tools and new techniques to decrease energy consumption. On the other hand, technological progress will increase economic growth which will then cause energy consumption. So it is very complex to explain the relation between technological progress and energy consumption. The relation between energy intensity and technological progress is shown in Fig. 1.

Pérez-Barahona and Zou (2006) analyze the hypothesis about the effectiveness of energy-saving technologies to reduce the trade-off between economic growth and energy preservation and show that positive growth is possible only if the growth rate of the energy-saving technological progress exceeds the decreasing rate of the energy supply. van Zon and Hakan Yetkiner (2003) extended the Romer model in two ways and concluded that in order to have energy efficiency growth and output growth under rising real energy prices, a combination of R&D and energy policy is called for. Ma et al. (2008) reveals Chinese energy intensity is increasing during the study period (1995–2004) and the major driver appears to be due to the increased use of energy-intensive technology. Boucekkine and Pommeret (2004) studied optimal capital accumulation at the firm level when technological progress is energy saving, and the optimal capital stock is shown to remain a decreasing function of the energy cost. Berglund and Söderholm (2006) provided an overview and a critical analysis of the literature on incorporating induced technical change in energy system models. Neij and Åstrand (2006) concluded that the information on the continuous performance of different policy instruments and their effects on the introduction and dissemination of new energy technologies, provided by this evaluation approach, is essential for an improved adaptation and implementation of energy and climate policy. These researches have studied the impact on energy consumption of technological progress, but they did not measure the effects quantitatively.

2. Model

The histories of the economic growth in the developed countries show that capital, labor, energy, and technological progress are the basic elements of economy growth. So economy growth model focuses on five variables: output (Y), capital (K),

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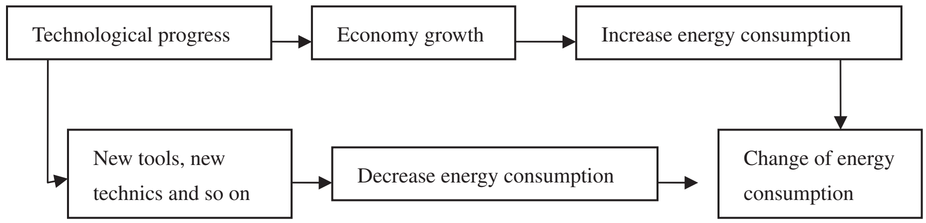

Fig. 1. Effect on energy consumption of technological progress.

labor (L), energy (E), and technological progress (T). Capital, labor, energy, and technological progress are combined to produce output. The production function takes the form

$$Y(t) = f(K(t), L(t), E(t), T(t)) \tag{1}$$

Assume that technological progress is exogenous and has a constant growth rate c, then technological progress grows exponentially

$$T(t) = Ae^{ct} \tag{2}$$

Cobb–Douglas production function is easy to analyze, and it appears to be a good approximation to actual productions (Romer, 2001). So Cobb–Douglas production function is used and it is shown as below

$$Y(t) = Ae^{ct}K(t)^{\alpha}L(t)^{\beta}E(t)^{\gamma} \tag{3}$$

Here α is the elasticity of output with respect of capital; β is the elasticity of output with respect of labor; γ is the elasticity of output with respect of energy and $0<\alpha,\beta,\gamma<1$.

Assume that the production function has constant returns to scale in its three arguments, capital, labor and energy, then

$$\alpha + \beta + \gamma = 1 \tag{4}$$

From Eq. (3), we can get

$$\left(\frac{E}{Y}\right)^{\gamma} \times e^{ct} \times A = \frac{Y^{1-\gamma}}{K^{\alpha}L^{\beta}} \tag{5}$$

Since $\alpha+\beta+\gamma = 1$, Eq. (5) is changed as below:

$$\left(\frac{E}{Y}\right)^{\gamma} \times e^{ct} \times A = \left(\frac{Y}{K}\right)^{\alpha}\left(\frac{Y}{L}\right)^{\beta} \tag{6}$$

Setting $\chi = E/Y$, which indicates energy consumption per output or energy intensity; setting $y_k = Y/K$ which indicates output per capital; setting $y_1 = Y/L$ which indicates output per labor.

Then Eq. (6) can be rewritten as

$$\chi^{\gamma} \times e^{ct} \times A = y_k^{\alpha} y_l^{\beta} \tag{7}$$

Calculate the natural log of the two sides of Eq. (7), and yields

$$\gamma \ln \chi(t) + ct + \ln A = \alpha \ln y_k(t) + \beta \ln y_l(t) \tag{8}$$

Calculate the derivative of the two sides of Eq. (8), and yields

$$\gamma \frac{\dot{\chi}(t)}{\chi(t)} = \alpha \frac{\dot{y}_k(t)}{y_k(t)} + \beta \frac{\dot{y}_l(t)}{y_l(t)} - c \tag{9}$$

$\dot{\chi}(t)/\chi(t)$ denotes the growth rate of $\chi(t)$(energy intensity); $\dot{y}_k(t)/y_k(t)$ denotes the growth rate of $y_k(t)$(output per capital); $\dot{y}_1(t)/y_1(t)$ denotes the growth rate of $y_1(t)$(output per labor); c indicates the growth rate of technological progress; a dot over a variable denotes a derivative with respect to time.

Eq. (9) shows that the growth rate of energy intensity was decided by the growth rates of output per capital, output per labor and technological progress and elasticity of output. The larger is the growth rate of output per capital and output per labor, the larger is that of energy intensity; the larger is the growth rate of technological progress, the smaller is that of energy intensity. When the influence of technological progress is larger than that of output, the energy intensity will decrease.

3. Data

Industry is an important sector in Chinese economy. The value added of industry occupies more than 40% of GDP in China. And energy consumption of industry occupies more than 70% of total energy consumption in China. So industry is selected as an example to be studied. Annual average balance of net value of fixed assets, annual average employed persons, energy consumption, value added of industry are shown in Table 1. Data in this table are calculated at current prices and should be changed at constant prices.

GDP deflator should be calculated at first before calculating value added at constant price.

$$\text{Indices of GDP} = \frac{\text{GDP at current price/GDP deflator}}{\text{GDP of preceding year}} \tag{10}$$

so

$$\text{GDP deflator} = \frac{\text{GDP at current price/indices of GDP}}{\text{GDP of preceding year}} \tag{11}$$

GDP at current price, indices of GDP, and GDP deflator calculated according to Eq. (12) are shown in Table 2. Annual average balance of net value of fixed assets at constant price is calculated according to investment of fixed assets price index. Investment of fixed assets price index is also shown in Table 2.

$$\text{Value added at constant price} = \frac{\text{Value added at current price}}{\text{GDP deflator}} \tag{12}$$

Annual average balance of net value of fixed assets at constant price

$$= \frac{\text{annual average balance of net value of fixed assets at current price}}{\text{investment of fixed assets price index}} \tag{13}$$

The values at constant prices calculated according to Eqs. (12) and (13) are shown in Table 3.

Due to the interference of some shock waves, the data collected sometimes may show too fast or too slow development tendencies, which do not reflect the true developmental tendency of the system. If this kind of data is used to build models without first eliminating the function of interference, the conclusion obtained are often unbelievable (Liu and Lin, 1998).

The Asian financial crisis broke out in 1997. It had an obvious shock on investment, energy consumption and economic growth as shown in Fig. 2. Annual average balance of net value of fixed assets and value added grew at a lower speed from 1997 to 2001. And energy consumption and annual average employed persons decreased continuously from 1997 to 2000.

Average weaken buffer operator (AWBO) which is shown in the appendix possesses some very good properties and has been