Energy 143 (2018) 812–821

Contents lists available at ScienceDirect

Energy

journal homepage: www.elsevier.com/locate/energy

How to promote energy efficiency through technological progress in China?

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A R T I C L E I N F O

Article history:
Received 6 July 2017
Received in revised form
3 October 2017
Accepted 7 November 2017
Available online 8 November 2017

Keywords:
Technological progress
Energy productivity
Structural transformation
Energy price
Dynamic panel data model

A B S T R A C T

Technological progress plays a key role in promoting energy efficiency. In order to find the suitable path of technological progress to improve energy efficiency, this study adopts the growth-accounting method to investigate the effects of two types of technological progress, namely, the Hicks-neutral and the capital-embodied technological progress on the changes in energy productivity. Furthermore, dynamic panel data models are applied to investigate the various effects of these two types of technological progress on energy productivities 30 Chinese provinces from 1997 to 2012. The main results are: (1) the Hicks-neutral technological progress directly contributes to energy productivity improvement, and its indirect contribution comes from the optimization of manufacturing structure induced by technological catch-up; (2) the capital-embodied technological progress has a direct contribution to energy productivity improvement, while the indirect contribution is seen through its interaction with the upgrading of the manufacturing structure; (3) the energy-saving performance from the capital-embodied technological progress is poor because of energy rebound effect. These findings suggest that the capital-embodied technological progress is effective for energy-saving in China; which can be made possible only by implementing energy price reforms.

1. Introduction

In 2014, the Chinese government explicitly proposed to actively promote an energy production and consumption revolution and implemented four strategies to achieve this goal. According to the *Energy Development Strategy Action Plan (2014–2020)*, which was released in November 2014, these four strategies include: an energy saving priority, dependence on domestic energy markets for energy supply, boost green and low-carbon economy and improvement in the level of innovation. Under this new energy strategy, technological progress is an important way of promoting energy revolution and upgrading of industrial structure. Achieving energy-saving through energy efficiency improvement has become a binding target of China's development, and technological progress and structural transformation are the two primary means available to the Chinese government to achieve the binding target [1–4]. The contribution of structural transformation to energy-saving is affected by economic development and economic fluctuations, and technological process is the biggest contributor to energy efficiency improvement in China [5,6].

Theoretical economics indicated that China's economic growth model, which is expressed as "investment-driven economic growth model", is unsustainable [7]. An important argument is that capital accumulation only has a level effect but does not have a growth effect, thus this growth model implies a low level of technological progress, making the Chinese growth model unsustainable and inefficient [8,9]. If this argument were true, China's technological progress would not adequately achieve the sustainability of energy efficiency improvement. However, the above view disagrees with China's fact. During the period 1997–2012, China's GDP increased by 4.01 times, but the total energy consumption increased by only 2.66 times. Thus, energy productivity (GDP per unit of energy input and measured by Yuan/tce constant 2000 prices) increased from

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https://doi.org/10.1016/j.energy.2017.11.047
0360-5442/

5801 to 8743, or increased by 50.71%. Also, many literature found that China's energy efficiency achieves a sustained improvement because of technological progress [10–12]. This contradiction means that China's technological progress does not seem to be at a low level. Due to the huge investment in China, one possible reason for the above contradiction is that the large-scale investment activities also involve significant embodied technological progress. In fact, the dynamic integration of capital accumulation induced by investment and technological progress is a stylized fact in China's economic growth. This suggests that this growth model has a low growth rate of Hicks-neutral technological progress, but is accompanied by a significant capital-embodied technological progress [13], and such technological progress may be the main driving force of China's energy efficiency improvement.

Some studies believe that technological progress will inevitably improve energy efficiency. However, it is not always true. Here are some arguments. 1) Some studies take the effects of total factor productivity (TFP) on energy efficiency as the whole effect of technological progress or technology change [14]. In other words, they ignore the fact that technological progress has different types [15]. In theory, TFP measures generalized and Hicks-neutral technological progress (hereafter neutral technological progress). Changes in TFP are not only affected by "narrow" technological progress or technology innovation, but also by economic policy, human capital, resource allocation efficiency and so on. Further, TFP assumes that technological progress and capital accumulation are independent; hence, it cannot effectively capture the changes in the quality of capital due to new machinery and equipment investment. In this sense, TFP ignores the capital-embodied technological progress that has been proven in China. 2) Some studies take the contribution of the results of technological progress to energy efficiency as the contribution of technological progress. Based on different structural decomposition methods or index decomposition techniques, most researchers conclude that energy intensities of sectors, which stand for technological progress, are the main reason for the improvement of China's energy efficiency [16–18]. Though changes in the energy efficiencies of sectors are closely related with technological progress, it does not equate to the latter. In fact, it is through the results of technological progress, factor substitution, structural changes within sectors and the energy mix changes. Hence, their results may be overestimating the effects of technological progress on energy-saving. 3) Most papers conclude that technological progress is conducive for energy efficiency improvement. Intuitively, the impacts of technological progress on energy efficiency are twofold. On the one hand, technological progress promotes economic growth for the given inputs, thereby increasing the output per unit of energy inputs. On the other hand, there are substitution effects between energy and other inputs when technological progress is biased, thus energy inputs will change for a given output [19,20]. The above analysis implies that for factor-biased technological progress, if the growth rate of energy inputs is faster than the output growth induced by this biased technological progress, this may lead to energy efficiency declining rather than rising, thus adversely affecting energy saving. 4) Because of rebound effect, the energy savings induced by technological progress will lower than the expected, so existing empirical studies may overestimate the contribution of technological progress to energy saving when ignore rebound effect [21–25]. Reducing the negative effects of the rebound effect on energy efficiency induced by technological progress, the main measure is increasing the cost of energy use, thereby reducing the substitution effect and income effect of technological progress on energy consumption. However, there are few papers that analyze the rebound effects of various types of technological progress.

From the above analysis, we find there are two types of technological progress, namely, the Hicks-neutral and the capital-embodied technological progress. They have different impacts on China's energy-saving, and the latter may be the main reason for China's energy efficiency improvement.

The study addresses several shortcomings in our understanding about the effects of technological progress on energy efficiency. First, the research design provides estimates of the impacts of different types of technological progress on energy efficiency. The capital-embodied technological progress and the neutral technological progress are defined and measured in a unified analytical framework, and as the core explanatory variables in empirical models to analyze their effects on energy efficiency of 30 Chinese provinces in 1997–2012. Also, the usage of dynamic panel data models and instrumental variables to address the endogeneity problem that can help to get the consistent relationship. Second, the multiplicative term of technological progress and industrial structure transformation in models can help to reveal the indirect effects of technological progress on energy efficiency through structural transformation. Third, considering energy rebound effects, the analytical method provides the suitable choice of the path of technological progress to promoting China's energy efficiency.

Although many studies analyze the impacts of technological progress on energy efficiency, few distinguishes the impacts of different types of technological progress. Furthermore, the literature about the indirect effects of technological progress on energy efficiency is rare. To the best of our knowledge, this is the first study to reveal the direct and indirect effects of different types of technological progress on China's energy efficiency.

The remainder of this paper is organized as follows. Section 2 presents the methods and variables. Section 3 is the econometric model. Sections 4 and 5 present the empirical results and discussion, respectively. The conclusions and political suggestions are provided at the end of this study.

2. Method and material

2.1. The impacts of two types of technological progress on energy efficiency

In this section, we present the theoretical analysis on the impacts of two types of technological progress, namely the capital-embodied technological progress and the neutral technological progress, on energy efficiency based on the growth-accounting method. According to economic growth models, the source of economic growth can be decomposed into three parts: technological change, technological catch-up and capital accumulation [26]. We illustrate these three parts by Fig. 1. The production function is $Y = f(K, L, E)$, and it means that output (Y) is produced by three inputs, namely capital stock (K), labor (L) and energy (E). Also, we assume that labor input (L) remains unchanged.

Technological change, which means changes in production technology induced by technical introduction or technical innovation, implies that the production frontier curve moves from line T to line T′, thereby output moves from point B to point C or point D to point F under the same inputs. Technological catch-up means efficiency improvement, or adopting the most efficient production methods or combinations of inputs to reduce production invalidity without changes in production technology, thereby causing output to move from the inefficient level to the efficient level. In Fig. 1(a), technological catch-up refers to output movement from point A to