Ecological Indicators 69 (2016) 758–770

Contents lists available at ScienceDirect

Ecological Indicators

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

Case study

Does directed technological change get greener: Empirical evidence from Shanghai's industrial green development transformation

Shuai Shao[a,*], Ranran Luan[a], Zhenbing Yang[b], Chengyu Li[a,*]

[a] School of Urban and Regional Science, Institute of Finance and Economics Research, Shanghai University of Finance and Economics, Shanghai 200433, China
[b] School of Economics, Nanjing University of Finance and Economics, Nanjing 210023, China

ARTICLE INFO

Article history:
Received 5 December 2015
Received in revised form 10 April 2016
Accepted 27 April 2016
Available online 3 June 2016

Keywords:
Directed technological change
Output elasticity of production factors
Green total factor productivity growth
Green development transformation
Stochastic frontier analysis

ABSTRACT

The degree of technological change biased to the environmental factor is crucial to industrial sustainable development. Using the stochastic frontier analysis method based on the translog production function and the panel data of 32 industrial sub-sectors in Shanghai over 1994–2011, this paper combines the evolution dynamic of the frontier technological structure with the evolution dynamic of technological change direction to estimate the output elasticities of production factors and the growth rate of green total factor productivity. Also, we investigate and compare the degrees of technological change biased to four production factors, i.e., capital, labor, energy, and carbon emissions. The results show that the industrial green total factor productivity in Shanghai presents an overall upward trend and mainly depends on the technical efficiency change. The improvements of labor productivity, R&D intensity, and energy efficiency can effectively enhance the green technical efficiency, while capital deepening has a mitigation effect on the green technical efficiency. The technological change of Shanghai's industrial production biases to energy use and capital saving, causing a high energy demand of industrial development. Under the dual impacts of economic development and energy-saving and emission-reduction policies, the degree of technological change biased to the environmental factor (carbon emissions) displays strong and weak alternations, indicating that the green bias of industrial technological change in Shanghai is not stable and that the green transformation of industrial development model needs to be further advanced.

1. Introduction

With the rapid economic development of China, a series of energy and environmental problems have appeared one after another. As the "world factory", China's carbon emissions have surpassed the United States and ranked the first in the world. As China is in the process of accelerated industrialization and urbanization, the rigid demand for energy consumption is difficult to effectively reduce. Hence, China's task of energy saving and emission reduction is very arduous. It is noteworthy that the extensive characteristic of China's economic growth based on the factors' expansion is particularly prominent in the industrial sectors. Since the reform and opening up in 1978, the industrial added value accounted for 40% of China's GDP along with about 67.9% of energy consumption and 83.1% of carbon emissions. Especially, with the emergence of re-heavy-industrialization[1] at the beginning of this century, industrial carbon emissions accounted for more than 90% of the

* Corresponding authors.
E-mail addresses: shao.shuai@sufe.edu.cn (S. Shao), li.chengyu@sufe.edu.cn (C. Li).

[1] China implemented its first "Five-Year Plan" from 1953 to 1957. During this period, the gross output value of heavy industry grew at an average annual rate of 15.5%, 5.5% higher than that of light industry (see *China Compendium of Statistics 1949–2008*). During 1958–1978, there were 17 years when heavy industry's output value share in the total industrial output value was higher than that of light industry. Especially in 1960, heavy industry's output value once accounted for 66.6% of the total industrial output value (see *China Compendium of Statistics 1949–2008*). Generally, such a process is called "heavy industrialization" in China. Since reform and opening up in 1978, China had changed such a strategy prior to the development of heavy industry and paid more attention to developing light industry, causing the decline in the share of heavy industry. Throughout the 1980s and almost the entire 1990s, the output value shares of light and heavy industry were both around 50%. However, since 1999, the growth rate of heavy industry's output value began to exceed that of light industry. In 2004, heavy industry's proportion rose to 67.6%, higher than its peak share of 66.6% in 1960 before 1978 (Zhu and Liu, 2006). Since then China stepped into a stage oriented by heavy industry prioritization. Therefore, such a stage is widely called "re-heavy-industrialization" in China.

http://dx.doi.org/10.1016/j.ecolind.2016.04.050

country's total carbon emissions (Chen, 2011). It is obvious that the rapid growth of China's industry has the characteristics of high investment, high energy consumption, and high emissions. The co-existence of rapid economic growth and serious environmental pollution causes that China's economic development model is referred as the "Black Cat" model rather than "White Cat" model (Meng et al., 2013).

Actually, the Chinese government has recognized that previous development patterns were not sustainable (Shao et al., 2011) and is implementing the new development planning of "New Path of Industrialization"[2] and "Scientific Outlook on Development"[3]. The domestic demand for the development model transformation and the international pressure on carbon emission reduction have prompted the Chinese government to propose the carbon emissions control target in 2009, i.e., by 2020, CO_2 emissions per GDP would drop by 40–45% relative to the 2005 level. This target has been introduced as a constraint indicator of long-term planning of national economic and social development. As a part of this target, China's 12th "Five-Year Plan" has put forward that CO_2 emissions per GDP should decline by 17% compared with the 2010 level. In particular, in the APEC CEO Summit 2014 in Beijing, China promised to hit carbon emissions peak around 2030 and try to get such a target as soon as possible. Moreover, to achieve such targets, the governments at different levels in China have adopted a series of relevant policies and stringent regulations. Hence, the proposal on carbon reduction is not only a challenge for China's economic development, but also a vital opportunity of economic transformation for achieving sustainable development (Fan et al., 2015).

Technological progress is one of the essential sources of economic growth, while the green technological progress is a long-term power of energy saving, emission reduction, and sustainable development (Jaffe et al., 2003). A consensus has been reached on the argument that technological change generally has the different biases to various factor inputs (Hicks, 1932). If technological change is biased to a certain factor, meaning that technological change can promote the marginal output growth rate of the factor input, then the production is preferred to use such a factor. Correspondingly, if the industrial production is preferred to use some polluting factor, it will be not conducive to industrial green technological progress. Therefore, when considering energy and environmental factors inputs, the investigation on the direction of technological change can help to judge whether the industrial production has transformed toward a green production model of energy saving and emission reduction, and accordingly, to provide the corresponding policy reference.

[2] This concept was proposed in the 16th National Congress of the CPC (Communist Party of China) in 2002 for the first time. In the Congress, China's former president, Zemin Jiang pointed out that one of the arduous historical tasks in the process of China's modernization is to accomplish industrialization. The application of IT (information technology) should be a rational choice of accelerating China's industrialization and modernization. Therefore, it is necessary to persist in employing IT to propel industrialization, which will, in turn, stimulate industrial informationization, impelling China to step into a new stage of industrialization characterized by more scientific and technological content, higher economic effectiveness, less resources consumption and environmental pollution, and greater human resource advantage. Such industrialization idea is called "New Path of Industrialization".

[3] This concept was raised by China's former president, Jintao Hu at the Third Plenary Session of the 16th Central Committee of the CPC in 2003 for the first time. The Scientific Outlook on Development has been included into the Party Constitution of the CPC as the CPC's guiding ideology. Also, it has been regarded as a significant guiding principle of China's economic and social development and as a major strategic thought that should be actualized in developing the socialism with Chinese characteristics. The Scientific Outlook on Development puts people as its core, regards comprehensive, balanced and sustainable development as its basic requirement, and takes social and economic sustainable development as its fundamental objective, including the harmonious development of human and nature.

When only considering the two inputs of capital and labor, the existing studies have investigated the directions of technological change by using various samples. Based on the CES (constant elasticity substitution) production function and the data of the United States over 1899–1960, David and Klundert (1965) calculated the direction of technological change and found that the overall technological change was biased to capital. Taking the United States data as the research samples, Wilkinson (1968), Sato (1970), and Klump et al. (2007) all drew the similar conclusions. Some studies took Finland, the Eurozone, and Japan as the investigated samples and also found that technological change biased to capital (Ripatti and Vilmunen, 2001; Klump et al., 2008; Sato and Morita, 2009). Regarding China, Dai and Xu (2010) and Lu and Zhang (2013) carried out the investigation on the direction of China's production technological change and also obtained the same results. Hence, existing studies indicate that when only considering the two inputs of capital and labor, technological change is generally biased to capital. However, under the condition of only considering capital and labor, previous studies are unable to examine the technological change preference to energy and environmental factors and fail to reflect the degree of green technological change.

Aiming at such a shortcoming, some researchers try to embed the energy factor into production function to examine the degree of technological change biased to energy factor. Acemoglu (2002) established a theoretical model to illuminate the internal mechanism of the development of clean technology. Otto et al. (2007) established a CGE model to investigate the energy-biased technological change and found that the technical change was biased to non-energy intensive products. Through the stochastic frontier analysis based the translog cost function, Hogan and Jorgenson (1991) and Sanstad et al. (2006) concluded that technological change had stimulated the demand for energy in the United States. With respect to China, Wang et al. (2014) and Wang and Qi (2014) found that the production technological change in China's industrial sector was biased to increase energy demand and energy intensity.

Overall, with the diversification of the considered input factors, in the studies on the direction of production technological change, the CES function with the constant substitution elasticity has been seldom used, while the translog function with the variable substitution elasticity is more and more popular. Numerous studies have shown that the translog function is closer to reality and more suitable to fit the data. For example, Altunbas and Chakravarty (2001) proved that such a function could be used to effectively deal with non-equilibrium or heterogeneous data to obtain more credible results. Moreover, since the translog production function allows variable substitution elasticities and is a second-order Taylor approximation or a second-order differential approximation of the general production function at a particular point (Wesseh and Lin, 2016), it is more suitable to calculate the biased technological change in this paper than the CES production functions. Moreover, although the existing studies have already focused on the degree of technological change biased to energy use, the investigation on the degree of technological change biased to the environmental factor in China's industrial sector is still absent.

As the economic center of China, Shanghai is regarded as an epitome of China's economic development process and is anticipated to play a leading role in the green transformation of development model in China. Regarding Shanghai's industrial sector, on one hand, the industrial sector remains the largest source of energy consumption and carbon emissions (Li et al., 2010; Shao et al., 2011; Wang et al., 2013a). *China Energy Statistical Yearbook* indicates that in 2011, the share of industrial final energy consumption in the total final energy consumption in Shanghai was about 55%, while the share of industrial CO_2 emissions in the total energy-related CO_2 emissions of five major sectors (i.e.,