Applied Energy 168 (2016) 351–363

Contents lists available at ScienceDirect

Applied Energy

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

Impact of energy conservation policies on the green productivity in China's manufacturing sector: Evidence from a three-stage DEA model

Ke Li [a,b], Boqiang Lin [b,*]

[a] College of Mathematics & Computer Science, Hunan Normal University, Changsha, Hunan 410081, PR China
[b] Collaborative Innovation Center for Energy Economics and Energy Policy, China Institute for Studies in Energy Policy, Xiamen University, Xiamen, Fujian 361005, PR China

HIGHLIGHTS

- A green productivity index is proposed by an improved DEA calculation method.
- A three-stage DEA model is used to evaluate the energy-saving regulations.
- From the energy saving perspective, China's policies and measures are effective.
- The environmental performance plays a decisive role in green productivity growth.

ARTICLE INFO

Article history:
Received 2 September 2015
Received in revised form 26 January 2016
Accepted 28 January 2016

Keywords:
Energy conservation policy
Green productivity
Malmquist–Luenberger productivity index
Three-stage DEA model
China

ABSTRACT

This study introduces an improved Malmquist–Luenberger productivity index to measure the green productivity growth of China's manufacturing sector during the 11th Five-Year Period (2006–2010). A three-stage data envelopment analysis model is adopted to measure the effects of government measures on green productivity growth. The main results are: (i) the average value of the Malmquist productivity index is 1.045 and the average value of the Malmquist–Luenberger productivity index accounting for CO_2 emissions is 1.027. This indicates imply that the relatively higher values of the former are at the expense of substantial energy usage and CO_2 emissions; (ii) China's energy-saving policies and measures, such as mass promotion and adoption of energy-saving technology, closure and elimination of obsolete production capacity, and reduction of over-capacity are important for green development; (iii) after eliminating the effects of environmental influences and statistical noise on output slacks, the adjusted green productivity changes are smaller while the adjusted technical changes are larger than the corresponding initial levels; (iv) the energy conservation policies implemented in China's manufacturing sector are far from the optimal level, and more stringent enforcement would be conducive for green productivity growth in the manufacturing sector.

1. Introduction

The Paris agreement, which is adopted by COP21 in 2015, also known as the 2015 Paris Climate Conference, aimes to achieve a legally binding and universal agreement on climate, with the aim of keeping global warming below 2 °C. Accordingly, the Chinese government submitted its Intended Nationally Determined Contribution (INDC), detailing its commitment to climate change mitigation and adaptation for the post-2020 period. According to China's INDC, it commits to building energy efficient and low-carbon industrial system, which requires to promote low-carbon development of industrial sectors. The specific measures include to effectively control emissions from key sectors through energy conservation and efficiency improvement, and strengthen the management of carbon emissions for new projects and to actively control greenhouse gas emissions originating from the industrial production process. In this sense, the green development of industry (especially the manufacturing sector) is critical for meeting the above commitments.

The manufacturing sector plays a critical role in China's economic growth. According to the National Bureau of Statistics of China, on the basis of the indicators of industrial enterprises whose principal business income are above 500 million Yuan per year, the number of enterprises, the gross industrial output values, taxes and other charges on principal business and the employees of the manufacturing sector accounted for about 93.31%, 87.26%,

* Corresponding author. Tel.: +86 5922186076; fax: +86 5922186075.
E-mail addresses: likekent1208@163.com (K. Li), bqlin@xmu.edu.cn, bqlin2004@vip.sina.com (B. Lin).

http://dx.doi.org/10.1016/j.apenergy.2016.01.104
0306-2619/

Nomenclature

APO	Asian Productivity Organization	LP	Linear Programming
BRICS	Brazil, Russia, India, China and South Africa	MLPI	Malmquist–Luenberger Productivity Index
DDF	Directional Distance Function	MPI	Malmquist Productivity Index
DEA	Data Envelopment Analysis	PPS	the Production Possibility Set
DMU	Decision-Making Unit	R&D	Research and Development
FYP	Five-Year Plan	SFA	Stochastic Frontier Analysis
GDP	Gross Domestic Product	TFEE	Total-Factor Energy Efficiency
INDC	Intended Nationally Determined Contribution	TFP	Total-factor Productivity
IPCC	Intergovernmental Panel on Climate Change	TRS	Target Responsibility System

85.58% and 87.92% of the industrial sector respectively[1] in 2010. Additionally, the manufacturing sector was also the main contributor to increment in energy use and CO_2 emissions. In 2010, it consumed 1.89 billion tons of standard coal and 2.287 trillion kilowatt hour of electricity, equivalent to 81.64% and 74.08% of total industrial consumption respectively. The sector also accounts for 58.29% and 54.54% of total energy and electricity consumption respectively. In the context of CO_2 emissions, the manufacturing sector emits 4.667 billion tons of CO_2, accounting for 56.67% of the total industrial CO_2 emissions. Hence, the key to China's sustainable development is tied to green development of the manufacturing sector.

The Chinese government has long recognized the importance and urgency of sustainable development through energy conservation and emissions abatement. The *Environmental Protection Law* (1979) was proposed to ensure the rational use of natural resources, and for the prevention and reversal of environmental pollution and ecological damage. Meanwhile, energy shortage was a major constraint to economic growth, and many enterprises adopted the "*Ting San Kai Si*" system (it refers to a situation where enterprises work three days a week because of energy shortage). It can be said that energy shortage was the major impetus for energy conservation at that time. In the 1980s, the Chinese government proposed "*both development and conservation are of importance, and the latter is the priority in the near future*". *The Law of Conservation of Energy*, which was promulgated in 1997, explicitly put forward "*energy conservation as a long-term strategic approach to national economic development*". This statement provides a legal framework for China's energy-saving action.

In the context of pollutants abatement, series of laws and regulations such as regulation of waste gas, waste water and solid pollutants during the process of industrial production were promulgated for environmental protection. *The Air Pollution Prevention and Control Law* explicitly requested the state to take measures to control or gradually reduce some major air pollutants. During the period 1979–2010, China introduced one-tenth of all laws (or 27 laws) in the area of energy and nature conservation [1].

Despite the abundance of laws and regulations on energy conservation and environmental protection, environmental degradation continues in China due to the poor implementation of them. Energy supply and environmental deterioration have become two major obstacles to sustainable development in China. Since 2006, the Chinese government has attached importance to energy conservation and emissions abatement, and has explicitly proposed "*establishing resources-conservation and an environment-friendly society*". The main approach is taking the reduction targets of energy intensity as one of the government's ambitious targets. These targets were implemented under the target responsibility system (TRS). Afterward, a series of regulations and measures were introduced to ensure the achievement of the above targets.

The purpose of this study is threefold. First, in the context of methodology, this study aims to contribute to the literature by improving the estimation method with the combination of the super efficiency data envelopment analysis (DEA) and sequential DEA technology. Thus, an improved Malmquist–Luenberger productivity index (MLPI) is proposed to measure green productivity growth. Second, a three-stage model is adopted to explore the impact of different levels of the enforcement of energy-saving regulations from the major aspects on green productivity growth of China's manufacturing sectors. Third, from an empirical research perspective, the conclusions and findings of this paper present an accurate green productivity growth of China's manufacturing sectors. More importantly, the paper proposes policies to enhance green development [2].

The rest of the paper is organized as follows. Section 2 reviews the energy-conservation policies in China. Section 3 is the literature review. Section 4 discusses the methodology of the study. Section 5 describes the variables and data. Section 6 presents the evaluation of the green productivity growth across China's manufacturing sectors. Section 7 discusses the results. Section 8 is conclusions and policy implications.

2. Energy-conservation policies in China

Table 1 presents a summary of the main energy-saving policies of China since 2006. During the period of the 11th Five-Year-Plan (11th FYP, corresponding the years of 2006–2010), the government clearly presented the reduction targets of energy intensity and its responsibility (1),[2] and illustrated the importance and the legal status of energy conservation (2, 9). The main measures include (i) speeding up industrial structure transformation through the control of the rapid development of energy-intensive industries by adopting strict land and credit policies. Some of these policies include removing backward production capacity through "*close backward production capacity and build large capacity and energy-saving enterprises*" (namely "*Shang Da Ya Xiao*" or "*Yi Da Zhi Xiao*", especially in the power generation sector), and promoting the development of tertiary industry (6); (ii) optimizing energy consumption structure through increasing the proportion of carbon-free energy in total energy usage (5, 8, 10); (iii) promoting energy conservation technology development through low-interest loan programs, tax reductions or exemptions, interest subsidies and so on (4, 7).

In 2011–2015, the government not only set the reduction target for energy intensity, but also formulated the reduction target for carbon intensity (CO_2 emissions per unit of GDP). They are expected to decline by 16% and 17% respectively in 2015 relative to their levels in 2010 (11). The specific measures include the upgrading and optimization of industrial structure (12, 13, 18), the de-carbonization of the energy mix (14, 16), and the promotion and adoption of energy-saving technologies (17, 19). In addition,

[1] It includes (i) mining and quarrying sectors, (ii) manufacturing sectors, and (iii) electric power, gas and water production and supply sectors.

[2] In this sub-section, the numbers in brackets refer the numbers in Table 1.