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Environmental efficiency and abatement cost of China's industrial sectors based on a three-stage data envelopment analysis

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ABSTRACT

China has gained the reputation of “global factory” due to its phenomenal industrial growth over the past decades. At the same time, its industrial energy consumption has resulted in serious environmental problems. Accordingly, there is an urgent and critical need to reduce industrial carbon emissions at a minimum cost without hampering the country's economic development. The dual targets for carbon emission intensity and amount from the 12th Five-Year (2011–2015) Plan make it necessary to investigate the environmental efficiency and reduction costs of different sectors. This study employs a three-stage data envelopment analysis model based on a directional distance function approach with radial and non-radial slacks of desirable and undesirable outputs considered to measure the environmental efficiency and marginal CO_2 emission abatement costs of China's 37 two-digit industries during 2005–2014. Based on the environmental efficiency and abatement cost of the industrial sectors, we reached the following conclusions. First, the adjusted estimates differ significantly from the results that do not consider the influence of environmental factors, and it is essential to consider the heterogeneity of industries in proposing emission reduction strategies. In addition, the stimuli for the smelting and pressing of metal industries result in cost reduction and the supervision on the top nine emitters and the Equipment Manufacturing Industries should be strengthened. Finally, the industrial sectors with large abatement potential are classified into short-term and long-term key target industries according to the emission abatement cost analyses.

1. Introduction

China has made remarkable progress in economic and social development in the past decades, at the same time its energy consumption has increased significantly. This reflects China's reputation as “global factory” and has led to serious environmental and ecological problems. This development mode is unstable and ultimately unsustainable.[1] Meanwhile, China's energy demands and CO_2 reduction activities have attracted worldwide attention. According to the International Energy Association (IEA, 2015), China was the world's largest fuel consumer and CO_2 emitter in 2013, with 3057 million tons of standard coal consumption and 8, 692 million tons of CO_2 emissions, which amounted to 22.51% and 27.00% of the world totals, respectively.

In common with the industrialization process in developed countries, China's economic growth has had an over-reliance on industry, especially high energy consumption industries[2] (HECs), resource mining industries (RMIs), and equipment manufacturing industries (EMIs). According to National Bureau of Statistics (2013), industrial fossil energy consumption has accounted for about 70% of the total national consumption in the past decades, of which more than 70% are attributed to the six HECs. Considering the key role of the industrial sectors in realizing the emission abatement targets, it is of great necessity and significance to study their relative environmental efficiency and reduction potentials of them. To

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[1] In the Government Work Report 2008 and 2013, the former premier Wen attributed this phenomenon to the past economic development model of favoring exports and investment over domestic consumption, capital over labor, state-owned enterprises over the private sector, and the economy over the environment.

[2] As reported in the National Economic and Social Development Statistics Report of 2010, the six high energy consumption industries are MOR, MONM, SAPOF, SAPONF, POP, and PADOE.

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Nomenclatures

DEA	Data Envelopment Analysis
DMU	Decision Making Unit
EMI	Equipment manufacturing industries
EOP	Extraction of Petroleum and Natural Gas
HEC	High energy-consumption industry
LTKT	Long-term key target industry
MAPOF	Mining and Processing of Ferrous Metal Ores
MAPONF	Mining and Processing of Non-Ferrous Metal Ores
MAPONO	Mining and Processing of Non-metal Ores
MAWOC	Mining and Washing of Coal
MOA	Manufacture of Articles for Culture, Education, Arts and Crafts, Sport and Entertainment Activities
MOAA	Manufacture of Artwork and Other Manufacturing
MOC	Manufacture of Chemical Fibres
MOCE	Manufacture of Computers, Communication and Other Electronic Equipment
MOE	Manufacture of Electrical Machinery and Apparatus
MOF	Manufacture of Foods
MOFU	Manufacture of Furniture
MOG	Manufacture of General Purpose Machinery
MOL	Manufacture of Leather, Fur, Feather and Related Products and Footwear
MOLBR	Manufacture of Liquor, Beverages and Refined Tea
MOM	Manufacture of Medicines
MOMI	Manufacture of Measuring Instruments and Machinery
MOMP	Manufacture of Metal Products
MONM	Manufacture of Non-metallic Mineral Products
MOP	Manufacture of Paper and Paper Products
MOR	Manufacture of Raw Chemical Materials and Chemical Products
MORP	Manufacture of Rubber and Plastics Products
MOS	Manufacture of Special Purpose Machinery
MOT	Manufacture of Tobacco
MOTEX	Manufacture of Textile
MOTE	Manufacture of Transport Equipment
MOTWA	Manufacture of Textile, Wearing Apparel and Accessories
PADOE	Production and Supply of Electric Power and Heat Power
PADOG	Production and Supply of Gas
PADOW	Production and Supply of Water
POFFAP	Processing of Food from Agricultural Products
POP	Processing of Petroleum, Coking and Processing of Nuclear Fuel
POT	Processing of Timber, Manufacture of Wood, Bamboo, Rattan, Palm and Straw Products
PROR	Printing and Reproduction of Recording Media
RMI	Resources mining industries
SAPOF	Smelting and Pressing of Ferrous Metals
SAPONF	Smelting and Pressing of Non-ferrous Metals
SFA	Stochastic Frontier Analysis
STKT	Short-term key target industry
UOW	Utilization of Waste Resources

achieve the emission reduction targets, China has developed many policies to accelerate the transformation from a traditional development mode to a green and low carbon one.

The imperative for a new mode of growth may also be reflected by the "new normal" economy outlined in 2014.[3] Under this mode China would focus on improving the quality and efficiency of the economy rather than just on the GDP growth, which highlights the need for structural reforms that would accelerate innovation and technological progress. The appeal of this mode coincides with the World Bank's (2012) "China 2030" report that stresses the benefits of green development. This is defined as a pattern of development that decouples growth from heavy dependence on resource use, emissions, and environmental damage and promotes growth through the creation of new green products, technologies, investments, and changes in consumption and conservation behavior (Chen and Golley, 2014). According to the *Statistics Bulletin of the National Economic and Social Development,* the total energy consumption of China in 2015 has reached 4 billion tons of standard coal and the energy intensity has decreased by 18.2% since 2011. Since the 12th Five-Year (2011–2015) Plan, China has put forward dual targets for energy consumption and intensity. For the intensity target, the environmental efficiency assessment could provide a comprehensive reference since it is a total factor productivity indicator with comparison to the single index of energy or emission intensity. With regard to the amount of energy and emission, the task decompositions among different regions as well as various production sectors are inevitably involved. That is, identifying the status and process of different sectors in energy saving and emission reduction is a matter of urgency for the dual targets. Recently, China made a further commitment to achieve a peak in its CO_2 emissions around 2030 (and to make its best efforts to peak earlier), and promised that its carbon emissions per unit of GDP in 2030 would decrease by 60%–65% compared with that of 2005. The key to achieving the emission targets is to scientifically estimate its reduction potential and emission costs for different industry sectors and then to formulate appropriate strategies.

The precondition for emission reduction policy-making involves evaluating the environmental efficiency and abatement cost of each industry. If focusing only on single index like carbon intensity, much important information of various industries on the operational status, specific characteristics and emission reduction costs would be ignored and the corresponding emission reduction strategy would be far from being comprehensive and convincing. The most common approaches to estimate efficiency can be classified into two broad groups: the parametric approach, such as the stochastic frontier approach (SFA) and the nonparametric approach, such as data envelopment analysis (DEA). Scholars compared DEA and SFA approaches from various angles (Nguyen et al., 2016; Reinhard et al., 2000). The very basic characteristics of them are as follows. With the SFA, a specific production function form is applied in order to estimate the inefficiency term (Aigner and Chu, 1968; Weyman-Jones et al., 2015). For DEA, the efficiencies of the decision making units (DMUs) can be measured without assuming any functional form of a representation of the production frontier (Charnes et al., 1978). There are many environmental efficiency studies for the whole or part of the industrial economy (Chung and Heshmati, 2015; Feijoo et al., 2002; Lee and Zhang, 2012). Baležentis et al. (2016) classified the Lithuanian

[3] The government gave a detailed explanation of the "new normal" economy in the APEC CEO Summit 2014. It has three characteristics: transition from high growth to moderate development; continuous optimization and upgrading of the economic structure; and transformation from factor and investment driven growth to innovation driven development.

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