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The approach to realizing the potential of emissions reduction in China: An implication from data envelopment analysis

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ABSTRACT

By proposing a three-hierarchy meta-frontier data envelopment analysis (DEA), this paper first decomposes CO_2-emissions efficiency and the potential for emissions reduction into the following three components: structural, technical, and management. Based on these components, we then conduct an empirical analysis of China's total-factor CO_2-emissions efficiency, its potential for CO_2-emissions reduction, and its corresponding implementation path. The results show that CO_2-emissions efficiency in Mainland China is relatively low because of structural inefficiency, technical inefficiency, and management inefficiency. The Chinese government is expected to realize a large quantity of CO_2-emissions reduction potential (nearly 40% of the current total CO_2-emissions) through adjusting the industrial structure, narrowing the technology gap among regions, promoting the reform of marketization, and strengthening environmental regulation. The causes of CO_2-emissions inefficiency and the distribution of potential reductions in emissions show a distinct spatial difference characteristic. Therefore, this paper also formulates emissions-reduction strategies for China's 30 provinces according to their specific situations, noting the direction of the industrial structure adjustment and the path to improving CO_2-emissions efficiency.

1. Introduction

Global greenhouse gases (GHGs), led by CO_2, have rapidly increased since the days of the Industrial Revolution. Accelerated global warming, which is caused by increasing concentrations of GHGs, is affecting global food production, human life, and the natural environment by changing the law of natural hazard occurrences. The fifth assessment of the Intergovernmental Panel on Climate Change (IPCC) notes that the core of preventing and controlling climate-change risk is to obtain a continuous decrease in GHGs emissions. However, according to the work of Friedlingstein et al. [1], global CO_2-emissions in 2013 were 36.1 billion tons, an increase of 2.3% over 2012. Specifically, China's total CO_2-emissions reached 10 billion tons, representing approximately 28% of global emissions. Additionally, the corresponding growth rate is more than twice the world's average level [1]. As the world's largest emitter of CO_2, China is experiencing severe pressure to reduce its emissions. Controlling CO_2-emissions and improving CO_2-emissions efficiency to achieve low-carbon development has become the major challenge for China's sustainable development.

Fortunately, the Chinese government has already noted the severity of the situation. Accordingly, it has established specialized agencies to address climate change, set forth explicitly binding targets for CO_2-emissions reduction in major planning programs, and made powerful commitments to CO_2-emissions reduction at many international conferences. In 2007, the Chinese central government established a leading group as the deliberation and coordination agency to response to climate change. The main task of the leading group consists of formulating national important strategies, principles, and countermeasures to respond to climate change and carrying out energy-saving and emission reduction policies; in 2008, the Chinese National Development and Reform Commission established a department to address climate change. During the 2009 UN Climate Change Conference in Copenhagen, the Chinese government committed to reducing CO_2-emissions intensity by 40–45% by 2020 based on 2005 levels; the Chinese "12th five year plan" (2011–2015) adopted a binding CO_2-emissions reduction target to reduce CO_2-emissions intensity by 17% by 2015 compared to 2010 levels. On March 24, 2015, a meeting of the CPC Central Committee Political Bureau proposed the political task of "Greenization" with the objective of guiding China's economy and society to develop in a green, low-carbon direction.

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In addition to establishing these meaningful departments, targets, and commitments, the Chinese government has also adopted practical measures to improve CO_2-emissions efficiency and reduce its CO_2-emissions. The adopted measures can be seen in China's 12th (2011–2015) and 13th (2016–2020) "five-year plan" and include adjusting China's industrial structure, promoting market-oriented reform, and strengthening environmental supervision. Actually, the 12th (2011–2015) and 13th (2016–2020) "five-year plan" both emphasize that promoting regional coordinated development, strengthening environmental protection, improving the socialist market economic system, and promoting the development of service industry are primary tasks of the Chinese government. The open question is whether these measures could improve CO_2-emissions efficiency and achieve CO_2-emissions reductions. If so, how effective could these measures be? Because of China's vast geographic expanse, China's regions exhibit extremely uneven levels of economic development, resource endowment, and economic structure. An additional question is whether there is a unified emissions-reduction strategy suitable for all of China's regions, or whether each region should adopt a strategy based on its specific situation. Thus, it is not difficult to understand that these issues are not only an important area of research but also a matter of considerable interest to China's policymakers.

The remainder of this paper is organized as follows. In Section 2, the relevant background and literature are presented. The extended DEA models for decomposing CO_2-emissions efficiency and the potential for emissions reduction are briefly introduced in Sections 3.1 and 3.2. Section 3.3 describes panel data used in the empirical study. The empirical results (CO_2-emissions efficiency and the potential for emissions reduction at both the national and regional levels) are presented and discussed in Sections 4.1 and 4.2. Section 4.3 provides a strategy of CO_2-emissions reduction for China's 30 provinces. Section 5 provides the conclusions and corresponding policy implications.

2. Literature review

Evaluating relative CO_2-emissions efficiency among regions/industries/enterprises not only helps us understand the differences among them but also provides an objective reference point for improving CO_2-emissions efficiency and determining the path to realizing the potential for emissions reduction [2]. With the recent intensification of global warming and the important role of China in the global CO_2-emissions reduction, issues related to China's CO_2-emissions efficiency and CO_2-emissions reductions have been garnering increased attention. The indicators used in the literature for measuring the efficiency of China's CO_2-emissions can be divided into two groups: (1) single-factor indicators (e.g., CO_2-emissions intensity); and (2) total-factor indicators (e.g., total-factor CO_2-emissions efficiency based on DEA).

The single-factor indicators are widely used to evaluate the CO_2-emissions performance because of their definitional intuitiveness and ease of use [3]. Based on single-factor indicators (e.g., CO_2-emissions intensity), several well-established decomposition methods (e.g., index decomposition analysis, IDA) have been used to analyze driving factors for the changes in CO_2-emissions efficiency. For instance, to capture driving forces responsible for the decline in China's primary energy-related CO_2-emissions intensity during 1980–2003, Fan et al. [4] used an Adaptive Weighting Divisia index method to decompose the fluctuation of CO_2-emissions intensity into four effects: industrial structural effect, energy structural effect, energy intensity effect, and emission coefficient effect. They found that the biggest contributor to the decline of China's CO_2-emissions intensity was the decrease in energy intensity, while the changes in industrial structure have significant negative impacts on the decline of China's CO_2-emissions intensity. To reveal the factors that influence the changes in China's CO_2-emissions intensity during 1991–2006, Zhang et al. [5] applied "the complete decomposition model" proposed by Sun [6] for breaking down the changes in CO_2-emissions intensity into four effects: industrial effect, energy intensity effect, emission coefficient effect, and economic activity effect. The results show that energy intensity effect is the biggest contributor to the decline in CO_2-emissions intensity, while industrial structure and emission coefficient effects increased CO_2-emissions intensity during the sample period. Also to identify the factors responsible for the decrease in China's CO_2-emissions intensity during 1998–2008, Tan et al. [7] utilized the Logarithmic Mean Divisia index (LMDI) method to decompose fluctuations of CO_2-emissions intensity into several effects and found that activities related to the electric power industry played a key role in the decrease of China's CO_2-emissions intensity and the provinces who have high emission levels contributed much more to this decline in CO_2-emissions intensity. Chen [8] applied the LMDI method to decompose the changes in China's CO_2-emissions intensity during 1980–2008 into four effects (the same as Fan et al. [4]) and found that energy intensity contributed the most to the reduction in CO_2-emissions intensity, while industrial and energy effects are very little. Guan et al. [9] utilized Laspeyres-Paasche index method to analyze the contributions of industrial CO_2-emission intensity and industrial structure to the changes of China's regional CO_2-emissions intensity between 2002 and 2009. The results indicate that during the period of 2002–2009, the decrease in industrial CO_2-emissions intensity in nearly all China's provinces were offset by movement towards a more carbon-intensive economic structure. Here, it should be pointed out that there are also a mass of literature using these decomposition methods for decomposing the changes in China's CO_2-emissions [10–14], but their research focuses are the changes in total CO_2-emissions, not CO_2-emissions efficiency.

Overall, based on single-factor indicators and decomposition methods, researchers are allowed to identify the impacts of structure (e.g., industrial and energy structure) and energy intensity changes on the aggregate CO_2-emissions intensity (similar judgements can be found in Ang [15] and Ang et al. [16]). Despite of these advantages, single-factor indicators have the drawback that without considering the roles of inputs in production activity, it cannot reflect the substitution effect between factors of production and the underlying production technology (similar judgements can be found in Wilson et al. [17]). For the same reason, Du et al. [3] pointed out that single-factor indicators such as CO_2-emissions intensity cannot reflect the distance between the current production state and the optimum production state and the real reduction potential of CO_2-emissions. Therefore, the single-factor indicators may be not ideal choices for CO_2-emissions efficiency evaluation.

In contrast, total-factor indicators are based total-factor framework in which inputs, desirable and undesirable outputs are all included. It is not difficult to conclude that compared to single-factor indicators, total-factor indicators are closer to the actual production process [3]. Actually, there are two main methods for evaluating total-factor indicators: one is the nonparametric method (e.g., DEA); the other is the parametric method (e.g., stochastic frontier analysis (SFA)). For example, Lee and Zhang [18], Wang et al. [19] and Lin and Wang [20] applied parametric methods for evaluating CO_2-emissions efficiency respectively in Chinese manufacturing industries, provinces, and iron & steel industry. However, Wang et al. [21] pointed out that as functional form requires subjective setting in the parametric methods while in the nonparametric methods no functional form is needed, the nonparametric method is superior to parametric methods for eliminating the influence of subjective factors. Thus far, total-factor indicators based on DEA have been widely utilized to explore CO_2-emissions-related issues (e.g., efficiency, reduction potential, and sources of efficiency changes). The review of DEA in energy & environmental studies also can be found in [2,22,23].

DEA is a mathematical procedure proposed by Charnes et al. [24] to assess the efficiencies of decision-making units (DMUs). As the reason that CO_2-emissions is one of by- and undesirable outputs, the tradi-