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Carbon emissions intensity reduction target for China's power industry: An efficiency and productivity perspective

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ABSTRACT

This paper proposes a scenario analysis to address whether the national and provincial CO_2 emissions intensity reduction target during 2016–2020 would be achievable for China's power industry with the identification of change on carbon productivity. This productivity indicator is further decomposed to investigate contributions of different sources to productivity growth when there exists technological heterogeneity. Evaluation results show that even if all electricity-generating units in each region were able to adopt the best practice, the nationwide 18% intensity reduction target is not feasible through improving technical efficiency or upgrading technology on electricity generation and carbon abatement in a short or medium term. The existence of regional technological heterogeneity in power generation and associated CO_2 emissions reduction processes implies the necessity of more differentiated regulations and policies for emission reduction across China's regions and inter-regional technology transfer. The emerging national emission trading scheme could easy some challenges in formulating emission policy for heterogeneous regions.

1. Introduction

Global warming and climate change has increasingly become a public concern and a serious challenge in energy policy-making for all governments. The temperature of global surface increased $0.74 \pm 0.18\,^{\circ}C$ during 20th century (IPCC, 2013). In the United Nations Framework Convention on Climate Change (UNFCCC) Conference of the Parties (COP) in Paris of 2015, there is a globally accepted target ($2\,^{\circ}C$) and ambition target ($1.5\,^{\circ}C$) for limiting global temperature rise.

The increase of fossil fuel consumption, which is the main driving force of global warming and climate change, has led to the global socio-economic development and large-scale CO_2 emissions (Chen et al., 2018). As the world's largest emitter of CO_2, China had announced a series of agreements and targets on climate change mitigation. For example, on the Copenhagen climate change summit in 2009, China announced that it would reduce its CO_2 emissions intensity of GDP (i.e., CO_2 emissions per unit of GDP) by 40–45 percent by 2020 relative to the 2005-level (Paltsev et al., 2012). Furthermore, in the COP 2015in Paris, the Chinese government had made three major commitments in its Intended Nationally Determined Contribution (INDC) regarding CO_2 emissions. The first is to peak its CO_2 emissions no later than 2030. The second is to reduce its CO_2 emissions intensity of GDP by 60–65 percent by 2030 relative to its 2005-level. The third is to increase the share of non-fossil energy in the total primary energy supply to 20 percent by 2030 (Bjorn, 2016). To meet these targets, China implemented a

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series policies and regulations in each Five-Year Plan (FYP) period. FYP, which is formulated by Chinese government, guides the national economy and social development and environmental protection. Table 1 presents some nationwide targets in 11th, 12th and 13th FYP. According the nationwide 18% reduction target, each province in China also implemented its regional CO_2 emissions intensity (i.e., CO_2 emissions per unit of total output value) reduction target of 13th FYP.

Achieving the CO_2 emissions intensity reduction target in China's electricity generation sector plays a crucial role in the national efforts to control CO_2 emissions and other air pollutants (Wang et al., 2016b, 2018b). According to the International Energy Agency (IEA, 2011), China's power sector, which is dominated by the consumption of fossil fuels and nonrenewable energies, accounts for about 50% of China's total CO_2 emission in 2010. Whether the CO_2 emission targets for the electricity sector is achievable is an issue that is important to the Chinese policy makers and the global community that is fighting with climate change. For the Chinese policy makers, another question, which is also significant for formulating the policies that promote the energy and environmental efficiency, is how to further reduce CO_2 emissions (Hampf and Rødseth, 2015).

The present paper has two aims. The first aim is to evaluate the feasibility of the nationwide (18%) and provincial CO_2 emissions intensity reduction target for China's power industry in 13th FYP given its existing technologies of generation and emission control. The second aim is to identify the ways in which the reduction targets can be reached from the perspective of productivity change. Thus, this study evaluates the carbon productivity of China's power industry in the 12th FYP period and identify the driving forces for their improvement.

An evaluation of carbon efficiency and productivity of power industry sector for China's 30 provinces is offered using an endogenous directional distance function (DDF) proposed by Färe et al. (2013) to identify the largest efficiency improvement potential and the meta-technology frontier approach to solve the problem of the technological heterogeneity among provinces. Understanding the technological frontier is significant for identifying the feasibility of CO_2 emissions intensity reduction target. Improving the carbon efficiency and productivity is an important way to achieve the CO_2 emissions intensity reduction target. Meanwhile, the factorial decomposition of productivity change in the past trends could help researchers to identify the drivers in objective variable, i.e., the reduction on CO_2 emissions intensity.

Existing studies on DDF and productivity change decomposition have faced several challenges. First, in most applications of DDF, the directional vector is selected by the researchers. This selection is arbitrary and does not guarantee capturing the largest efficiency improvement potential (Adler and Voltab, 2016; Wang et al., 2016a). Second, most of the existing studies applying meta-frontier technique only analyzed the group differences from the spatial dimension perspective (Oh, 2010; Hančlová and Melecký, 2016; Barros and Wanke, 2017a,b; Feng et al., 2018). In other words, most researchers only employed the cross-sectional data to do an analysis. Hence, the other dimension perspective, that is the temporal perspective, should be considered into the meta-frontier technique to do some further analysis. Third, the existing scenario analysis and decomposition analysis only focused on the decomposition of productivity change into efficiency change and technical change (i.e., best practice gap change) (Du et al., 2014; Lee et al., 2015; Lin and Zhao, 2016). Therefore, more drivers need be explored in the productivity evaluation via scenario analysis.

This study makes the following contributions to the existing literature at the theoretical and the application level. First, the endogenous DDF approach provides a more reasonable evaluation of the CO_2 emissions intensity reduction target in China's power industry through identifying the largest efficiency improvement potential. Second, the meta-technology technique takes into account the technological heterogeneity of different power industry sectors across China's regions, providing a more proper estimation of the driving forces of carbon productivity growth in China's power industry. Third, this study takes both the spatial dimension and the temporal dimension into consideration via scenario analysis, presenting a more comprehensive investigation on the productivity change from the perspective of technical efficiency change (*TEC*), best practice gap change (*BPC*), and technological gap change (*TGC*). Fourth, this is the first study to examine the feasibility of emission target for China's power generation sector in 13th FYP and investigate additional policy option to achieve the target.

This reminder of this paper is organized as follows: Section 2 is the literature review. Section 3 introduces the methodology including the production and environmental technologies and endogenous efficiency estimation method, the meta-technology frontier approach, and the Luenberger productivity indicator and its decomposition. Section 4 presents the empirical study of the examination of the feasibility of CO_2 emissions intensity reduction target and the identification of productivity change in China's power industry. Section 5 concludes the study.

2. Method

In this study, to measure the carbon efficiency and productivity, the nonparametric DDF approach based on the DEA technique is employed to estimate the technologies. An endogenous efficiency measure is proposed for Luenberger productivity indicator of meta-technology and its decomposition. A brief explanation of the technical issues will be presented in the next three sub-sections and the scenario design will be explained in section 2.4.

2.1. Production and environmental technologies and endogenous efficiency estimation

By considering a production process of $j = 1,2, \ldots,n$ observed power industry sectors at provincial level, each province comprises a vector of input $\boldsymbol{x}_j = (x_{1j}, x_{2j}, \ldots, x_{ij}, \ldots, x_{mj}) \in R_+^m$, a vector of intended (or good) outputs $\boldsymbol{y}_j = (y_{1j}, y_{2j}, \ldots, y_{rj}, \ldots, y_{sj}) \in \boldsymbol{R}_+^{\boldsymbol{s}}$, and a vector of unintended (or bad) outputs $\boldsymbol{u}_j = (u_{1j}, u_{2j}, \ldots, u_{fj}, \ldots, u_{hj}) \in \boldsymbol{R}_+^{\boldsymbol{h}}$. The production possibility set $\boldsymbol{T}$ of this production process is a

Table 1
Nationwide targets on energy conservation and carbon control.

Periods	Reduction targets	
	Energy intensity (SCC, 2007; SCC, 2011a)	CO_2 emissions intensity (SCC, 2011b; SCC, 2016)
11^{th} FYP (2006–2010)	20%	–
12^{th} FYP (2011–2015)	16%	17%
13^{th} FYP (2016–2020)	–	18%

Note: Energy intensity is final energy consumption per unit of GDP; CO_2 emissions intensity is CO_2 emissions per unit of GDP.