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Measuring environment-biased technological progress considering energy saving and emission reduction

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ABSTRACT

This study proposes a mathematical definition of environment-biased technological progress that can evaluate energy saving and emission reduction abilities. Further, it proposes the concepts of absoluteness and relativity, while extending the classical non-radial slack-based measure in order to establish an advanced slack-based measure model. In addition, a super-efficiency advanced slack-based measure model is set up to test the effectiveness and growth rate of environment-biased technological progress in China. Finally, with China entering a new normal since 2012, economic growth data for 1890 coal production enterprises for 2012–2014 are collected to measure the conditions of environment-biased technological progress in each location and registration type. The results indicate that, compared to existing methods, the proposed method is useful and universally applicable.

1. Introduction

With accelerated modernization, the ecological environment on which human beings rely has been confronted with various unprecedented threats. In particular, the emission of hazardous pollutants has severely restrained economic growth. In November 2015, the relevant departments of 195 countries signed the Adoption of the Paris Agreement on diverse subjects—for example, emission, reduction and mitigation, adaption, damages and losses, funds, technologies, capability building, degree of transparency, and global reckoning—with an aim to reduce losses in and damages caused to the ecological environment by carbon emissions. China is the second largest economic entity in the world, but with a high emission rate. Following high-speed economic growth since the reform and opening-up, deteriorating environmental quality caused by an extensive development model has gained significant attention. While there is an urgent need to transform China's development model, such conditions are difficult to change in the short run, especially since the Chinese economy is at a critical stage of urbanization. Moreover, its traditional industrial structures are rigid and have high demands for energy sources. To address this issue, the Fifth Plenary Session of the 18th CPC Central Committee proposed that green and sustainable development should be advocated and maintained for a safe and efficient modern energy system. China's citizens are paying increasing attention to the relationship between environmental protection and economic growth and have played a key role in the enactment of environmental regulations and policies (Do Paço et al., 2009; Glucker et al., 2013). Many scholars agree that technological change is a driving force in stimulating economic growth and improving environmental quality. Taking appropriate measures to define and implement the principles of sustainability during production processes is critical in realizing improvements in environmental management (Fernando and Wah, 2017; Maryam et al., 2017).

With the deepening of research, some scholars established the endogenous technological change theory. Drawing on these studies,

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Acemoglu (1998, 2002, 2003, 2007) further established the theory framework of biased technological change, calling it directed technological change (DTC), in which biased technological change that stimulates energy saving and emission reduction is known as environment-biased technological progress (EBP) (Acemoglu et al., 2012a). If EBP increases, costs of energy saving and emission reduction will reduce, which means enterprises can obtain higher emission-reduction benefits with less pollution treatment expenses. Theoretically, EBP can shed light on important phenomena, such as the labor–employment structure (Song and Wang, 2016), interstate income gap (Acemoglu et al., 2015), and environmental technological change (Aghion et al., 2012). However, a standard method to precisely measure EBP is still lacking, although it has been theoretically defined and proved by Acemoglu et al. (2012a, b). The realization of a precise measurement and improvement in the efficiency of technological change can support the enactment and implementation of the principles of energy saving and sustainable environmental development during production processes (Halkos and Tzeremes, 2013). In this case, the conservation of resources and improvement in environmental quality can be simultaneously achieved. Studies have proposed methods to measure EBP, including time trend (Arnberg and Bjorner, 2007; Ma et al., 2008, 2009), GDP-trade ratio (Welsch and Ochsen, 2005), and the distribution of government spending between education and infrastructure (Harrison, 2002). However, these studies adopt various substitutive indicators that lead to significantly ambiguous evaluation results. Research has also attempted to adopt the non-parametric estimation method to measure biased technological change using data envelopment analysis (DEA) and its extended models (Song et al., 2014), although the results express overall technological change, and not the degree of bias in technological change.

The industry 4.0 that we advocate today is for transforming the original mass and homogenized industrial production to small-batch and individualized production to satisfy the demands of different consumers. Similarly, the problem of heterogeneity also exists due to different economies, cultures, and politics in different enterprises and areas, and similar technological R&D input can lead to different technology progress. Therefore, the amount of biased technology progress in different enterprises or areas and how to precisely measure it are the key problems to us. Therefore, an axiomatic method system to measure EBP is needed in the field of biased technological change measurement. Thus, in this study, we propose a method to measure EBP considering energy saving and emission reduction.

The remainder of this paper is structured as follows. Section 2 is a literature review. Section 3 describes the construction of the EBP model. Section 4 measures the EBP of each area examined in China, and Section 5 offers concluding remarks.

2. Literature review

The literature has paid significant attention to measuring technological change and improving its growth rate. Given its various advantages, a non-parametric estimation method popularly used to measure technological change is the DEA (Bogetoft and Wang, 2005; Chung et al., 1997). For example, it does not require preset production functions, reveals hidden or ignored relations in environmental systems (Liu et al., 2010), and quantitatively analyzes the low efficiencies of non-effective decision-making units (Lv et al., 2013). Although DEA theory has significantly developed over the years, there remains a lack of mature axiomatic methods to measure EBP. In this section, we discuss the theory and measurement of EBP, efficiency evaluation of heterogeneous DEAs, and summary and prospect of current situations.

Biased technological change can be traced back to Hicks' theory of wages, in which he pointed out that the objective of technological innovation is to save decreasing production factors. Kennedy and Thirlwall (1972) later proposed the innovation possibility frontier from the viewpoint of technological provision, and that the frontier determines bias in technological change. Recent studies have adopted Solow's model of endogenized technological change as a micro basis, and considered technological change to be biased rather than Hicks neutral, also known as the redeveloped theory of biased technological change (Aghion and Howitt, 1992). Acemoglu (2003) noted that biased technological change includes labor- and capital-enhanced technological change. The former refers to the outward movement of the yield curve parallel to the coordinates of capital caused by technological change, that is, the same type of labor can be combined with more capital for production. The latter refers to the outward movement of the yield curve along the coordinates of labor. According to Acemoglu's (2003) definition, biased technological change caused by adding different technological change rates to capital and labor in the Solow production function, is the quotient of the capital-labor marginal income ratio and technological change ratio. If the quotient exceeds zero, technology is capital biased; if not, it is labor biased.

With growing public attention toward environmental issues, recent research has accounted for environmental factors reflecting living quality in the production functions. However, biased technological change concerning environmental and production factors tends to differ. The former requires outputs to increase in line with technological change, while the latter requires energy consumption and undesirable outputs to decrease (Wang and Song, 2014). Mannea and Richels (2004) examined the influence of biased technological change on the cost and time of CO_2 emission reduction from an output perspective by introducing biased technological change in their climate change model and considering that various technological costs decrease with an increase in experience. Popp (2004) introduced biased technological change in the energy sector in a dynamic integrated climate-economy model to evaluate climate change, and computed the welfare cost of optimum carbon tax. Acemoglu et al. (2012a) introduced EBP in their growth model with environmental and resource constraints, and conducted a cost-benefit analyses of different environmental policies while accounting for clean and pollutive technology. In the same year, Acemoglu et al. (2012b) established the endogenous growth model for EBP from the viewpoint of input to emphasize the dearth in input research. The above discussion reiterates the importance of theoretical research on EBP for production and daily living practices. A comprehensive understanding of these theories can help in the smooth implementation of measurements, and is an effective guarantee for environmental management work.

DEA can be used to strengthen the production frontier, objectively reflect reality (Song and Wang, 2015) without being limited to formats, and explain hidden or ignored conditions. Many scholars have adopted DEA to measure biased technological change. It is also widely believed that its non-parametric feature renders it a better option than parametric estimation methods, such as stochastic frontier analysis (Kou et al., 2016). Environmental scholars have also attempted to establish a new DEA model to measure EBP. Using the DEA model, Chambers et al. (1996) proposed the Luenberger productivity index with an additional structure to measure technological change with environmental elements. Chung et al. (1997) constructed the directional distance function that considered both an increase in desirable outputs and decrease in undesirable ones and set up the Malmquist–Luenberger