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Evaluating the method of total factor productivity growth and analysis of its influencing factors during the economic transitional period in China

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ABSTRACT

This paper proposes a method for the evaluation of total factor productivity (TFP) based on the super-efficiency Data Envelopment Analysis (DEA) model and the Malmquist–Luenberger index. Under China's constraints for carbon emissions, data sampled from eight cities in two large areas in Anhui Province in central China, namely the Wan Jiang region and the northern Anhui region, from 2001 to 2009 were cited as the sample for the analysis of the low-carbon TFP index. An analysis of the low carbon index changes and composition during the period of economic transformation was also conducted. The empirical analysis results indicate that the technical efficiency change has a lower effect on the progress of total factor productivity and that technological progress exerts the dominant force in total factor productivity growth. This study also performed Hausman tests of the factors influencing the total factor productivity and suggested advances in certain policies accordingly.

1. Introduction

As the world's largest developing country, China clearly declared a plan for emissions reduction at the United Nations Climate Change Conference in Copenhagen in 2009: to reduce greenhouse gas emissions by 40%–45% per unit of GDP by 2020 compared with that in 2005 and to integrate the index as a binding force into the national economic and social development in medium-to long-term planning (referred to Ang (1999)). Nonetheless, China is now in a period of industrialization, and the demand for fossil fuels continues to rise. Therefore, the economic development constitutes a conflict against carbon emission reduction, and the transformation of the pattern of economic development is the only way to solve this conflict. Accordingly, guidelines of developing plans should be transformed from the “fast and good development” to “sound and rapid development,” which has become the priority of the Chinese economy for achieving sustainable development (Zhao and Mao, 2011). The thinking of sustainable development is to improve the total factor productivity's contribution to the economic growth and to attempt to minimize the adverse effects of the economic activities on the environment. The proper assessment of the economic development performance must take into consideration the influence of environmental factors on the basis of traditional productivity research.

In traditional economic growth theory, the examination and assessment of economic growth is conducted from the perspective of production function, and the continuous improvement of the elements of accumulated stock and total factor productivity is regarded as the main means for the promotion of economic growth (Wang et al., 2009). At present in China, there exist various quantitative analysis methods to measure TFP, and two views are represented in these methods. The first view is the Solow residual method, which first estimates the contribution rate of the promoting factors in economic growth to the production function (excluding technical factors) and then deducts the weighted value of each factor's growth rate from the GDP growth rate such that the remaining balance is the TFP (Guo 2005). Using this method, it is difficult to distinguish each of the components of total factor productivity growth. The second view is the data envelopment analysis (DEA) method. By measuring the relative efficiency frontier of input to output, the traditional total factor growth rate can be determined through the Malmquist index measurement (Yan 2004). The two traditional methods have one point in common: to build an aggregate production function in which the input variables include capital, labor, energy, etc., and the output variable is the GDP (Sun et al., 2010).

There is an obvious problem in the traditional research literature: under the carbon emissions constraints, without considering

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the amount of CO_2 emissions, energy consumption was not taken into account in the construction of the total production function of economic growth. China is now undergoing a rapid development of industrialization and urbanization, and its energy demand continues to increase. Thus, the amount of CO_2 emissions will also increase as China's economy continues to develop. Because carbon emission constraints may result in a negative effect on the economy's potential output scale (Chen, 2010), the traditional TFP measurement method based on this scale has an obvious flaw: the total factor productivity is obtained by the expected output (GDP) growth rate minus the contribution value of the input (Wei et al., 2007). If the unexpected output (CO_2) is produced in production, the influence of the TFP on unexpected output changes is not taken into consideration, which produces deviations associated with the use of this method to measure the TFP (Repetto et al., 1997). However, the goal of low-carbon economy development requires an increase in the expected output and a control of the unexpected output. In all, the measurement of the TFP demands the simultaneous consideration of economic growth and fleet emissions (Mahlberg et al., 2011).

As the contradiction between economic development and environmental pollution becomes increasingly acute, some academics have considered environmental factors when measuring the TFP. For example, Hailu and Veeman (2000), when measuring the Canadian paper industry productivity, included the pollution administration fee in the model as a type of input. Their study shows that pollution has a negative impact on productivity, but the model was unable to distinguish correctly between the input resources that are used for pollution control. Seiford and Zhu (2005) established a multi-output DEA model and attempted to handle CO_2 emissions as another unexpected output in the production function through data transformation. However, this "output increase, pollution decrease" design method cannot be adopted to flexibly handle the influence of various factors on the total factor productivity (Zhou et al., 2010). To solve this problem, Chung et al. (2002) proposed the Malmquist–Luenberger productivity index for the measurement of the Swedish pulp mill productivity, and this type of analytical method takes into consideration not only the expected output but also the influence of the unexpected output on productivity by organically integrating the TFP and environmental pollution into the unified analysis framework.

Based on the existing literature, this study attempted to expand the field of study based on the following aspects: (1) to construct a super-efficiency DEA model based on the traditional DEA model and environmental factors in order to determine the total factor productivity index under the carbon emissions constraints based on the direction of distance function (DDF), (2) to re-estimate the low carbon total factor productivity index using the Malmquist–Luenberger productivity index theory and analyze the low carbon index changes and composition during the period of economic transformation based on panel data from Anhui Province from 2001 to 2009, and (3) to conduct Hausman tests of the factors that influence the total factor productivity because the existing studies do not perform a thorough empirical analysis of low-carbon total factor productivity. The findings were compared with the expected results.

2. Research method and model explanation

2.1. The super-efficiency DEA theory

From the perspective of total factor input–output, the DEA model is considered to measure the total factor productivity in the existing literature. There exists an obvious flaw in the use of the traditional DEA analysis method for the evaluation of the efficiency of decision-making units, namely, multiple decision-making units will be located in the production possibility frontier, which leads to the relative effectiveness of those multiple decision-making units such that none is superior to another. To compensate for this defect, Anderson (1995) improved the DEA model based on the original model and the effective discrimination between the high efficiency and low efficiency of each decision-making unit to obtain an investment-orientated super-efficiency DEA model. The specific operation mechanism is shown in Fig. 1. If the efficiency value of point A needs to be determined, point A should be ruled out of the reference range of the decision-making units, the frontier of the production possibilities would then be changed from EACD to EFCD, and the efficiency value of point A would be OF/OA > 1. Point G is an invalid point in the original DEA model, and its frontier of production possibilities is still EACD with a value consistent with that in the traditional DEA model, i.e., OB/OG < 1.

In the super-efficiency DEA model, if there are n decision-making units and m input variables, S outputs are obtained, as is shown in the super-efficiency DEA model equation of linear programming:

$$\min\left[\theta-\varepsilon\left(\sum_{i=1}^{n}S_i^- + \sum_{r=1}^{s}S_r^+\right)\right] \tag{1}$$

$$s.t. \sum_{\substack{j=1\\ j\neq k}}^{n}\lambda_j x_{ij}+s_i^- = x_{ik}\theta; \sum_{\substack{j=1\\ j\neq k}}^{n}\lambda_j x_{ij}-s_r^+ = \gamma_{rk}; s_i^-, s_r^+ \geq 0$$
$$j=1,2\cdots n; i=1,2\cdots m, r=1,2\cdots s.$$

In the equation, i refers decision-making unit i, t is the time variable, and ε is an infinitesimal value of Archimedes.

2.2. Directional Distance Function (DDF)

The essence of the low-carbon economy is to achieve CO_2 emission reduction targets under the premise of an economic growth guarantee. Thus, applying the traditional Shephard distance function to measure the total factor productivity may produce a deviation (Chung et al., 1997). When considering the environmental factors, a special input and output structure could be set up to contain both the "expected" output (Y) and the "unexpected" output (B). Using this basis, Luenberger (1992) and Chung et al. (1997) introduced the Directional Distance Function (DDF) and combined the expected output (Y) and the undesired output (B) into a unified analysis framework. The directional distance function shows that, under the established production technology level, the optimal proportion of input to output variables can be achieved, and the relative production efficiency of each decision unit can be measured. The specific principles are shown in formula (2) and in Fig. 2:

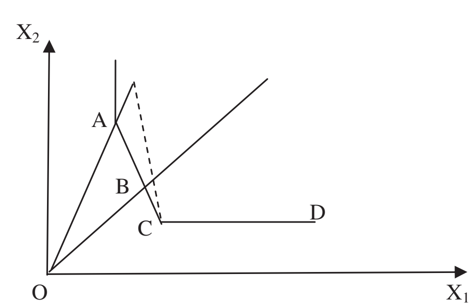

Fig. 1. Investment-orientated super-efficiency DEA model.