Technological Forecasting & Social Change 112 (2016) 228–236

Contents lists available at ScienceDirect

Technological Forecasting & Social Change

Environmental catching-up, eco-innovation, and technological leadership in China's pilot ecological civilization zones

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ARTICLE INFO

Article history:
Received 24 December 2015
Received in revised form 5 May 2016
Accepted 14 May 2016
Available online 25 May 2016

Keywords:
Environmental total-factor productivity
Metafrontier non-radial Luenberger productivity indicator
Poyang lake Eco-economic Zone

ABSTRACT

In this study we propose a global metafrontier Luenberger productivity indicator (GMLPI) to investigate the effect of the establishment of the Poyang Lake Eco-economic Zone (PLEEZ), one of China's typical ecological civilization zones, on regional environmental total-factor productivity growth. We combine the global environmental technology, metafrontier approach, and the non-radial Luenberger productivity indicator and incorporate the regional heterogeneities into the environmental productivity growth analysis. This GMLPI includes the efficiency change, technological change, and metafrontier technology gap change indices. An empirical study of the PLEEZ has been conducted using the county level data covering a period from 2009 to 2013. Empirical results show that the environmental productivity growth has increased by 8.71% on average, with growth primarily driven by technological change. These results suggest that the establishment of the PLEEZ is effective in encouraging eco-innovation; however the PLEEZ lacks an eco-leadership effect. Significant heterogeneities in environmental productivity growth and its patterns among three major functional zones in the PLEEZ remain.

1. Introduction

The Poyang Lake Eco-economic Zone Planning was officially approved by the State Council of China on December 12th, 2009, indicating that the construction of the Poyang Lake Eco-economic Zone (PLEEZ) was a national-level strategy. The PLEEZ is based on the Poyang lake urban circle and is intended to become an ecological economic demonstration zone and a low-carbon economy development priority zone in China.[1] The increasing interest in and strategic importance of the PLEEZ have heightened the need for investigating its effects on regional environmental performance.

Therefore this study investigates the effect of the PLEEZ's establishment on regional environmental productivity growth after 2009. A significant growth of the environmental productivity of the PLEEZ after 2009 indicates that the PLEEZ policy is effective.

Two kinds of indices are widely used for measuring productivity growth, i.e. the Malmquist index and the Luenberger indicator. The Malmquist index, empirically presented by Färe et al. (1994), is widely used for measuring productivity change growth. Taking the environmental factors into account, Chung et al. (1997) proposed the Malmquist–Luenberger index for measuring environmentally sensitive productivity growth. Empirical studies applying the Malmquist–Luenberger index include Weber and Domazlicky (2001), Färe et al. (2001), Yörük and Zaim (2005), Kumar (2006) and Zhang and Choi (2013a,b), for measuring environmental performance change.

The Luenberger productivity indicator is an alternative for measuring productivity growth. Compared with the Luenberger indicator, the Malmquist index appears to overestimate productivity changes (Boussemart et al., 2003). Recent work also suggests that the Luenberger index is more robust than the Malmquist index (Fujii et al., 2014). Thus, this study employs the Luenberger indicator as its main methodology. However, the basic Luenberger indicator cannot deal with the non-zero slack variable problem because it adopts the radial method for measuring performance (Zhou et al., 2012; Zhang et al., 2014). To handle this shortcoming, Fujii et al. (2014) proposed the non-radial Luenberger indicator with undesirable outputs. To incorporate cross-group heterogeneity into this indicator, Zhang and Wei (2015) introduced a metafrontier non-radial Luenberger carbon emission performance index; unlike Zhang and Wei (2015), who focused on single-factor carbon emission performance change, we propose a metafrontier

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[1] For details about the PLEEZ, please see Appendix A.

http://dx.doi.org/10.1016/j.techfore.2016.05.010
0040-1625/

non-radial Luenberger productivity indicator to measure the total-factor environmentally sensitive productivity growth. Compared with the methodologies adopted in existing energy and environmental studies (e.g. Wang et al., 2013, 2015; Zhang and Wei, 2015),[2] the key innovativeness of the proposed approach is that it can handle both non-zero slack variables and cross-group heterogeneity simultaneously. We then use the proposed approach to measure environmental productivity growth and its patterns in the PLEEZ at a county level.

This study has two major contributions to the current literature. Practically, although a number of studies have focused on the environmental productivity growth for China's provinces (Zhang et al., 2011; Choi et al., 2015) or China's industries (Chen and Golley, 2014; Li and Lin, 2015), no studies have explored the PLEEZ, a national-level strategy. This study thus addresses this research gap by evaluating the PLEEZ, thus enabling us to get insight into the effectiveness of this national-level strategy. Methodologically, we develop an integrated methodology called the Global Metafrontier non-radial Luenberger Productivity Indicator (GMLPI) to measure environmental productivity growth. This methodology combines a non-radial directional distance function, Luenberger productivity indicator, and the global metafrontier approach. It can thus incorporate slack variables, undesirable outputs, and group heterogeneities when measuring environmental productivity growth.

The remainder of this paper is organized as follows. Section 2 introduces the methodology used. Section 3 conducts the empirical study. Section 4 concludes this study.

2. Methodology

2.1. Non-radial directional distance function

We assume that there are $j = 1, \ldots, N$ observations, which are different counties in the PLEEZ, and each region uses input vector $x \in \Re_+^M$ to produce good economic output vector $y \in \Re_+^S$ as well as undesirable pollutant vector $b \in \Re_+^J$. Thus, the environmental production technology can be expressed as follows:

$$T = \{(x, y, b) : x \text{ can produce } (y, b)\}, \tag{1}$$

where T is the environmental production technology. We assume that it satisfies the standard axioms of production theory (Färe and Grosskopf, 2005). That is, finite amounts of inputs can produce only finite outputs. Inputs and desirable outputs are often assumed to be freely (strong) disposable. For modeling joint-production technologies (Färe et al., 1989) with undesirable outputs, weak disposability and null-jointness assumptions should be imposed on the environmental production technology T, as follows:

(i) If $(x,y,b) \in T$ and $0 \leq \theta \leq 1$, then $(x,\theta y,\theta b) \in T$;
(ii) If $(x,y,b) \in T$ and $b = 0$, then $y = 0$.

The weak-disposability assumption implies that pollutant abatement activities are costly in terms of proportional reductions in product output. Meanwhile, the null-jointness assumption indicates that the pollutants are not avoidable in the PLEEZ unless economic activities are stopped.

Following the literature, a piecewise non-parametric linear frontier is adopted to construct the environmental production technology. The environmental technology T for N observations with constant returns to scale may then be expressed as follows:

$$\begin{aligned} T = \{(x, y, b) \quad : & \sum_{n=1}^{N} z_n x_{mn} \leq x_m, m = 1, \ldots, M, \\ & \sum_{n=1}^{N} z_n y_{sn} \geq y_s, s = 1, \ldots, S, \\ & \sum_{n=1}^{N} z_n b_{jn} = b_j, j = 1, \ldots, J, \\ & z_n \geq 0, n = 1, \cdots, N\}. \end{aligned} \tag{2}$$

where M, S and J denote the number of inputs, desirable outputs and undesirable outputs, respectively.

After defining the environmental technology, the non-radial directional distance function (DDF) is followed. The formal definition of the non-radial DDF was first introduced by Zhou et al. (2012). Compared with other energy and environmental modeling techniques, a unique advantage of DDF is its capability of expanding desirable outputs and lessening inputs or undesirable outputs simultaneously. A review of DDF application in energy and environmental studies can be found in Zhang and Choi (2014). Following Zhou et al. (2012), the non-radial DDF with undesirable output is defined as:

$$\vec{D}(x, y, b; g) = \sup\{\mathbf{w}^T \boldsymbol{\beta} : ((x, y, b) + g \cdot diag(\boldsymbol{\beta})) \in T\}. \tag{3}$$

where $\mathbf{w} = (w_m^x, w_s^y, w_j^b)^T$ denotes a normalized weight vector corresponding to the number of inputs and outputs, $g = (-g_x, g_y, -g_b)$ is an explicit directional vector, and $\beta = (\beta_m^x, \beta_s^y, \beta_j^b)^T \geq 0$ denotes the scaling factors indicating the inefficiencies. Thus the value of $\vec{D}(x, y, b; g)$ under the environmental technology can be calculated by solving the following DEA-type model:

$$\begin{aligned} \vec{D}(x, y, b; g) = & \max\left(w_m^x \beta_m^x + w_s^y \beta_s^y + w_j^b \beta_j^b\right) \\ \text{s.t.} & \sum_{n=1}^{N} z_n x_{mn} \leq x_m - \beta_m^x g_{xm}, m = 1, \ldots, M, \\ & \sum_{n=1}^{N} z_n y_{sn} \geq y_s + \beta_s^y g_{ys}, s = 1, \ldots S, \\ & \sum_{n=1}^{N} z_n b_{jn} = b_j - \beta_j^b g_{bj}, j = 1, \ldots J, \\ & z_n \geq 0, n = 1, 2, \cdots, N \\ & \beta_m^x, \ \beta_s^y, \beta_j^b \geq 0. \end{aligned} \tag{4}$$

The directional vector g can be set up in different ways, based on given policy goals. If $\vec{D}(x, y, b; g) = 0$, then the specific unit to be evaluated is located on the frontier of the best practices in the direction of g.

2.2. Global metafrontier Luenberger productivity indicator (GMLPI)

Following Zhang and Choi (2013a,b) and Zhang and Wei (2015), three environmental technologies: contemporaneous, intertemporal, and global environmental technologies are needed to define the GMLPI and its decompositions.

The contemporaneous environmental technology for group R_h at time t is defined as $T_{R_h}{}^c = \{(x^t, y^t, b^t) : (x^t) \text{ can produce } (y^t, b^t)\}$, where $t = 1, \ldots, T$. The intertemporal environmental production technology of group R_h is defined as $T_{R_h}{}^I = T_{R_h}{}^1 \cup T_{R_h}{}^2 \cup \ldots \cup T_{R_h}{}^T$. The intertemporal environmental technology can be interpreted as the single technology set that encompasses all contemporaneous environmental technologies from whole period only for the specific group R_h. The global environmental production technology is defined as $T^G = T_{R_1}{}^I \cup T_{R_2}{}^I \cup \ldots \cup T_{R_H}{}^I$, which is constructed from all observations over the whole period for all groups. This implies that the global environmental technology encompasses all intertemporal environmental production technologies,

[2] For a comprehensive review please see Zhang and Choi (2014).