Energy Economics 32 (2010) 146–157

Contents lists available at ScienceDirect

Energy Economics

journal homepage: www.elsevier.com/locate/eneco

A metafrontier approach for measuring an environmentally sensitive productivity growth index

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ARTICLE INFO

Article history:
Received 21 April 2009
Received in revised form 25 June 2009
Accepted 8 July 2009
Available online 25 July 2009

JEL classification:
D24
C61
O57
Q43
Q56

Keywords:
Environmentally sensitive productivity growth index
Malmquist–Luenberger productivity growth index
Technical change
Efficiency change
CO_2 emissions

ABSTRACT

This paper presents an alternative environmentally sensitive productivity growth index to incorporate group heterogeneities into a conventional Malmquist–Luenberger productivity growth index. The proposed approach allows the calculation of both efficiency and technical changes, for economic agents operating under different technologies. Moreover, it also enables the computation of changes in the technological gap between regional and global frontier technologies. The proposed index is employed in measuring productivity growth and its decomposed components in 46 countries between 1993 and 2003. The main finding is that Europe has taken the lead in the world frontier technology and that Asia has attempted to move towards the frontier technology. Subsequent policy implications are provided based on some empirical studies.

1. Introduction

As international concerns on climate change and sustainable economic growth increase, global cooperation on environmental regulations, such as the Kyoto Protocol and the Bali Roadmap, has significantly increased. Since the international regulations for emissions of by-products affect economies at the state level as well as the regional level, environmental policies are required to be connected with national and regional economic policies. In order to formulate effective environment-related economic policies, research with different foci has been demanded to measure the relationship between the emissions of by-products and economic growth. This research includes both theoretical approaches and empirical studies.

Among methodologies utilized in examining the relationship between the emissions of by-products and economic growth, the environmentally sensitive productivity growth index has long been regarded as a pioneering tool. Its usefulness originates from the fact that it provides a measure of the economic prosperity, standard of living and environmental amenity of a country. Ever since the seminal work by Chung et al. (1997), the Malmquist–Luenberger productivity growth index (hereafter, ML index) has been used in various research fields for the following reasons: (i) It only requires quantities on the input/output bundles without demanding information on the costs of inputs/outputs; (ii) It does not impose any functional form assumptions on the production function; and (iii) It enables the productivity growth to be decomposed into several components, e. g., efficiency and technical changes. The ML index uses a linear programming technique in calculating the environmentally sensitive productivity growth index, which extends the Malmquist productivity index to incorporate the effect of environmentally harmful by-products. Moreover, the ML index considers by-products as *outputs*, alleviating bias in measuring the environmentally sensitive productivity growth index.[1] Thanks to these methodological merits, the ML index has been frequently utilized, not only at the micro-level but also in macro-level studies.

Regarding empirical studies using the ML index at the micro-level, Chung et al. (1997) is the first one. They analyze productivity growth

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[1] Before the introduction of the ML index, environmentally harmful by-products were often used as inputs.

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doi:10.1016/j.eneco.2009.07.006

and its decomposed sources of Swedish paper and pulp mills for the period 1986–1990. Their empirical result suggests that technical change is the main contributor to productivity growth rather than efficiency change. Using micro-level panel data, Färe et al. (2001) employ the ML index to account for both the marketed output and the output of the pollution abatement activities in the US state manufacturing sectors from 1974 to 1986. Weber and Domazlicky (2001) apply the same methodology to investigate the productivity growth in the US manufacturing sector for the period 1988–1994 in order to incorporate toxic release into the productivity analysis. Pasurka (2006) employs the ML index and decomposes the productivity growth of US coal-fired electric power plants into several factors. By doing this, he calculates the relative importance of factors associated with changes in NO_x and SO_2 emissions. Nakano and Managi (2008) measure productivity in Japanese steam power-generation sector to examine the effects of industrial reforms on the productivity for the period 1978–2003.

Compared to the numerous empirical studies at the micro-level, to our knowledge, only two studies incorporate undesirable outputs into the productivity analysis at the macro-level. Yörük and Zaim (2005) employ both the Malmquist productivity index and the ML index in order to analyze the productivity growth and its decomposed sources in OECD countries for the period between 1985 and 1998. They found that Ireland and Norway were the best performers and that technical change was the main contributor to productivity growth. Kumar (2006) employs the ML index to analyze the environmentally sensitive productivity growth of 41 countries for the period between 1973 and 1992. In his study, Kumar (2006) found that the productivity growth of Annex-I countries are higher than that of the non-Annex-I countries, and that technical change was the main contributor to productivity growth.

In spite of its wide use, the conventional ML index's weakness is that it does not consider *ex ante* heterogeneities among groups when calculating the rate of productivity growth. Instead of including the *ex ante* group heterogeneities when calculating productivity growth, the ML index calculates the productivity growth and then uses the *ex ante* group heterogeneities. However, if they are not included in the calculation of the ML index, the productivity growth rate may be biased for the following reasons. Since heterogeneity among groups leads to different production environments, the production activities of decision making units (DMUs) of one group is different from those of the other groups. That is, each group has its own production technology that determines the production activities of the DMUs in that group. As Battese et al. (2004) indicate, the productivity of the DMUs that operate under a given production technology are not directly comparable to those of the DMUs operating under a different technology. Without taking into account this group heterogeneity, the measured productivity is likely to be biased. Hence, the conventional ML index needs to be revised in order to properly consider group heterogeneity.

To overcome the aforementioned shortcoming of the ML index, in this study we provide an alternative index for measuring environmentally sensitive productivity growth by revising the conventional ML index. The proposed productivity growth index not only deals with the environmentally harmful by-products, but also properly incorporates the *ex ante* group heterogeneities into the process of calculating productivity growth. It also has the aforementioned merits of the conventional ML index. We combine the conventional ML index with the concept of the metafrontier for this methodological development.

The metafrontier is the envelope of the commonly conceived production frontiers, which is introduced by Battese and Rao (2002) and further elaborated by Battese et al. (2004). Battese and Rao (2002) introduced the concept of the metafrontier in order to solve for the incomparability of the performances of various groups. With this concept, they investigated the technical efficiencies of firms in groups that have different technologies. Battese et al. (2004) introduced a modified model assuming a single data-generation process based on Battese and Rao (2002). This framework was employed in analyzing the efficiencies of the Indonesian garment firms in five regions, where they assumed five different production groups.

To our knowledge, the productivity growth index proposed in this study is the first attempt to incorporate group heterogeneities into the environmentally sensitive productivity growth index. Methodologically, this index extends the metafrontier Malmquist productivity index of Oh and Lee (forthcoming) so that it can also incorporate environmentally harmful by-products. The proposed productivity growth index can be decomposed into three individual measures: efficiency change (the catching-up effect), technical change (the innovation effect) and technical leadership change (technological leading effect). Besides incorporating group heterogeneities, one strength of this index is that it provides a measure of the technical leading effect. We named this proposed index “the metafrontier Malmquist–Luenberger productivity growth index” (hereafter, MML index). The parametric metafrontier approach of Battese et al. (2004) is similar to the MML index in that both of the two approaches employ the concept of the metafrontier. However, the former is methodologically different from the latter for the following reasons. First, the parametric metafrontier approach deals with only a single output case. Hence, a multi output case, including undesirable outputs, cannot be considered in the parametric approach in general. Second, in the parametric metafrontier approach assumptions about the functional form are necessary, whereas in the MML index they are not. Third, the parametric metafrontier approach employs an econometric technique, whereas the MML index uses a linear programming technique. This means that the former estimates performance indexes while the latter calculates performance indexes.

The proposed index is employed to measure the environmentally sensitive productivity growth, efficiency change, technical change and technical leadership change of 46 countries over the 1993–2003 period. Data for this empirical investigation were retrieved from the Penn World Table and the World Bank Development Indicators databases. The aim of this empirical study is to investigate the productivity and decomposed components of the production activities originating from the group heterogeneities across continents, by considering CO_2 emissions. Empirical results show the following. First, European countries are good at innovating and creating technologies, indicating that energy- and environment-related technology developments are mainly led by the European countries. Second, Asian countries are good at catching up with frontier technologies by using input factors in an efficient way. Third, Ireland, Hong Kong and Switzerland emerge as global innovative countries. Fourth, environmentally sensitive productivity has diverged between the Americas, Asia and Europe.

The remainder of this paper is organized as follows: Section 2 provides an overview of the methodology; Section 3 describes the data set as well as presents the empirical results; and Section 4 concludes this study.

2. Methodology

The methodology we utilized in this study augments the basic assumptions of the ML index, laid out below. The underlying assumptions are introduced in Section 2.1, followed by the definitions of a directional distance function in Section 2.2. Our MML index, along with the conventional ML index, is presented in Section 2.3. An issue on measuring the MML index is illustrated in Section 2.4.

2.1. The underlying assumptions

Under a panel of $k=1,\ldots,K$ countries and $t=1,\ldots,T$ time periods, the production technology for countries producing M desirable outputs, $\mathbf{y}\in R_+^M$, and J undesirable outputs, $\mathbf{b}\in R_+^J$, by using N inputs,