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Measuring green productivity of country: A generlized metafrontier Malmquist productivity index approach

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ABSTRACT

This paper measures environmental productivity in 70 countries over the period 1981–2007. Differences in green (environmental) productivity growth across countries under distinct country specific production frontier are measured using directional distance function model, which incorporates desirable output (GDP) and undesirable output (CO_2 emissions). The metafrontier which envelops the two country groups, developed countries and developing countries, are estimated using balanced panel data for the sample countries over the study period. A parametric method is used to compute technical efficiency change, technical change, and scale efficiency change, which aggregate to the generalized metafrontier Malmquist productivity index. The overall results indicated the two country groups operated under distinct stochastic production frontiers and therefore used different production technologies. It is found that developing countries achieved higher growth in their average environmental productivity relative to the metafrontier. Thus the results coincide with the convergence growth theory.

1. Introduction

In this paper we apply recently developed techniques to investigate green (environmental) productivity growth for a sample of 70 countries over the period 1981–2007. The approach adopted allows us to decompose productivity growth into three mutually exclusive components: technical efficiency change, technical change, and scale efficiency change. These components capture catching up effect, technical innovation, and contribution of scale economies, respectively.

Our measure of productivity growth is an extended form of Malmquist productivity index, which was first introduced by Caves et al. [1] and further developed by Färe et al. [2] and Orea [3]. Technical efficiency change (catching Up) and technical change (innovation) allow us to test two contrasting theory of productivity growth, namely convergence growth theory and endogenous growth theory. Furthermore, scale efficiency change lends itself to the identification of scale economies. The level of scale efficiency is computed using the ratio of directional distance function values corresponding to constant and variable returns to scale technologies.

We calculate the component directional distance functions of the Malmquist productivity index using parametric methods. Our technique constructs an overarching metafrontier based on the data from all of the countries in the sample [4,5]. Each country is then compared to the metafrontier. How much closer a country gets to the metafrontier is what Färe et al. [2] called "catching up"; how much the metafrontier shifts given each country's observed input mix is what called "technical change" or "innovation". In what direction and at what magnitude each country move along the production frontier is called "scale efficiency change". The product of these three components yields a frontier productivity change index.

We apply our method to a sample of countries, which were divided into two groups, over the study period. Group 1 contains 35 developed and newly industrialized countries and group 2 contains 35 developing countries. We find that, over the sample period, group 1 exhibits higher volatilities in all component changes but lower annual average growth rate than group 2. The results of technical efficiency change and technical change favor convergence growth theory.

The remainder of this paper is organized as follows. Section 2 contains a review of the current literature on how to include undesirable outputs in parametric models and how to estimate productivity growth across different groups of countries using metafrontier. Section 3 outlines the research methodology of this paper. Section 4 describes the research data and specifies the

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empirical model. Section 5 reports the empirical results and section 6 concludes the paper.

2. Literature review

Productivity growth has been of interests to researchers and policy makers since it is the engine which drives the economic prosperity, standards of living and the competitiveness of a country. Though various theories have been proposed for the explanation of productivity growth in developed and developing countries, two are of particular interest to the present study. First, the convergence theory claimed that there is a general tendency for per capita income or total factor productivity (TFP) in low income countries to converge towards those of high income countries [6]. The rationale behind this theory is based on the concept of diminishing returns to scale. As well demonstrated in the work of Solow [7], the capital-labor ratio in the developed countries is founded to be high in comparison to that of developing countries and therefore the marginal productivity of capital in them should be low.

The contrasting viewpoint which embedded its rationale in the theory of endogenous growth states that per capita income or productivity of low and high income countries stays constant or even diverges over time. The foundation of this theory lies in the concept of increasing return to scale. It was advocated by the pioneering work of Arrow [8] and was further developed by Romer [9] and Lucas [10] that increasing returns to scale are generated from externalities associated with the acquisition of technical knowledge. According to endogenous growth theories, even if the individuals and firms face diminishing returns, spillover effect allows technical knowledge to diffuse and accrue to other firms and thus exhibits increasing return to scale at the aggregate level.

Recent concerns about the impact of economic development on the environment and the sustainability of economic growth has attracted economists to consider the environmental sensitive measures of productivity growth. However, traditional measures of productivity growth does not account for environmental deteriorating pollutants or by-products such as CO_2 emissions. It is conventionally measured using index numbers, which require data on prices of all inputs and outputs. The problem with this approach is that price information, especially those for undesirable outputs, usually does not exist. To overcome such problems, the productivity can be measured using a distance function as it requires data on quantities only on inputs, outputs and pollutants. Couple of previous studies estimated productivity using the distance function focusing on desirable outputs only (e.g. [2,11–13]). Färe et al. [2] used a nonparametric programming method to compute Malmquist productivity indexes of 17 OECD (Organisation for Economic Co-operation and Development) countries. Decomposition of the index into technical efficiency changes (catching up effect) and technological changes (innovation) enables attributing productivity growth to its sources of change and thus allows testing hypothesis for different growth theories. Moreover, Barros and Managi [11] mentioned that non-parametric frontier methods are much more flexible than other techniques estimating productivity because no a priori function of technology and no limitations on input remuneration, and could capture productive inefficiency and provide a standard baseline for comparison.

Zhou et al. [14] considered that it is necessary to take undesirable outputs into account when estimating the relationships between energy and environment. There are several studies used firm level data to measure efficiency and productivity change with the presence of undesirable outputs (e.g. Refs. [14–20]). Some of these studies treated pollution as one of the inputs in the production function [21–25], while others (e.g. Ref. [26]) reformulate the pollution as a desirable output. Atkinson and Dorfman [27] pointed out that this approach creates a different non-linear transformation of the original variable in the absence of base constrained emission rates. To solve this problem, Pittman [28] proposed that desirable and undesirable outputs should be treated non-symmetrically.

Chung et al. [16] provide the basis to represent the joint production of desirable and undesirable outputs by extending the Shephard's output distance function to the directional output distance function. The merit of directional output distance function is that it can be used to measure the polluting decision making unit's (DMU) efficiency and productivity in increasing desirable output and reducing undesirable output, namely pollution, because it allows one to expand one output and contract another output simultaneously. A growing literature has emerged since 1990s using the directional distance function to estimate the environmental efficiency and productivity at macro-economic as well as at micro-economic level [29–36].

The productivity index developed in the literature has two shortfalls, however. First, it does not provide an accurate measure of productivity change because it ignores the contribution of scale economies [3]. Since the directional distance function deals mainly with production technology operating in a multi-input multi-output context, it is to be expected that the input and output-*mix*, other than levels of input and output quantities, might play a certain role in the measure of productivity change. Suppose that the feasible input–output quantity combination, i.e. the technology, does not change, and that the DMU is technically efficient, that is, operating on the boundary. Then the DMU's productivity can nevertheless change by moving along the boundary and make use of its curvature [37]. The present study follows Balk's [37] and Orea's [2] approach to develop a generalized Malmquist productivity index to measure and analyze productivity growth of countries taking into account of the scale efficiency effect.

Second, these studies treat all the DMUs as a homogeneous group using the same production technology. Differences in technology and in resource availability which influence the productivity and efficiency of DMUs are ignored, and environmental efficiency and productivity are normally estimated using a pooling approach. In practice, abatement of the pollution requires transformation of production technologies and consumes resource and energy, which is expected to cause some costs. The costs of pollution abatement and its impact on productivity are likely to vary across countries due to differences in technology and resource availability [32]. However, because none of these papers, at least to our knowledge, distinguish environmental efficiency and productivity of different country groups in terms of specific features of their production technologies, the results of these papers might be, to some extent, misleading.

In this paper we apply a directional distance function approach that incorporates both desirable output (GDP, Gross Domestic Product) and undesirable output (CO_2) to provide a measure of Green (environmental) productivity as well as a measure of Environmental Efficiency (EE). The advantage of this function is that it allows one to consider nonproportional changes in output, since it is possible to expand desirable outputs, while contracting the undesirable outputs. According to Tuttle and Heap [38], the concept of green productivity was first introduced by the Asian Productivity Organization (APO) following the 1992 Rio Earth Summit:

> Green productivity (GP) is a strategy for enhancing productivity and environmental performance simultaneously to achieve overall socio-economic development.

Following the dual focus of the Asian view of the productivity, we take into account both desirable output and undesirable output when developing the measures of Green Productivity (GP) and EE so that both economic growth and environmental performance are