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Dynamics of productivity taking into consideration the impact of energy consumption and environmental degradation

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ABSTRACT

This study deals with the nonparametric frontier analysis in the case of the EU 28 countries for a period spanning from 1993 to 2015. It provides statistical inference about the radial output based measure of technical efficiency under the assumption of Constant Returns to Scale (CRS) and it performs scale analysis that allows determining the nature of scale inefficiency of each data point. Furthermore, an order-α approach is developed for determining partial frontiers. Both traditional Malmquist-Luenberger and bootstrapped Malmquist productivity indexes between 1993 and 2015 are constructed. Analysis of productivity change by decomposing the Total Factor Productivity Index into Efficiency Change and Technical Change is performed showing respectively whether productivity gains derive mainly from improvements in efficiency or are mostly the result of technological progress. In this sense, the results can provide European policy makers with an improved understanding of the process of technological and efficiency change helping them to improve the design of their environmental and energy policies.

1. Introduction

In the literature there are two approaches of productivity analysis, namely the neoclassical and the frontier approaches. The first one is based on standard neoclassical production function models as first developed by Solow (1956) and Swan (1956). The greatest weakness of neoclassical models is the limitation of their analysis to purely economic variables of capital and labor, ignoring natural resources, which is shown to be a travesty of reality as highlighted by Jefferson (2015). The second approach which focuses much on the importance of energy in the growth process can be implemented by a mathematical programming technique, as conducted in the present study, known as Data Envelopment Analysis (hereafter DEA) or through an econometric specification known as Stochastic Frontier Analysis. In contrast with the neoclassical approach which cannot distinguish a movement towards the efficiency frontier and a movement of the latter, the production frontier literature with a focus on DEA method attempts to deal with this issue.

DEA method has been widely used in evaluating technical and allocative efficiency of Decision Making Units (DMUs) in terms of relating inputs with outputs (Lovell, 1993; Seiford, 1997, 1996). DEA relies on a linear programming method to define technical efficiency (TE) levels, under constant (CRS) (Charnes et al., 1978) or variable (VRS) (Banker et al., 1984) returns to scale.

An important point to note is that DEA method as a non-parametric technique, cannot distinguish between noise and inefficiency. Several methods to cope with the usual misspecification and measurement problems due to statistical noise and outlier DMUs have been proposed (see among others Simar, 2003; Simar and Wilson, 1998; Wilson, 1995, 1993).

Various applications of DEA and of the Malmquist productivity index are utilized to calculate the performance of different DMUs over time in the presence of undesirable outputs. The latter are in the form of environmental degradation either as damages in the nature or pollutants' emissions (see among others Kortelainen, 2008; Mahlberg et al., 2011; Long et al., 2015; Sueyoshi and Goto, 2017; Chang, 2015; Chen and Jia, 2017; Lozano and Gutiérrez, 2008; Sanz-Díaz et al., 2017; Beltrán-Esteve and Picazo-Tadeo, 2017; Wu et al., 2012; Xie et al., 2014, 2015; Zhou et al., 2010; Zhou and Ang, 2008).

However, research on production function under the lines of

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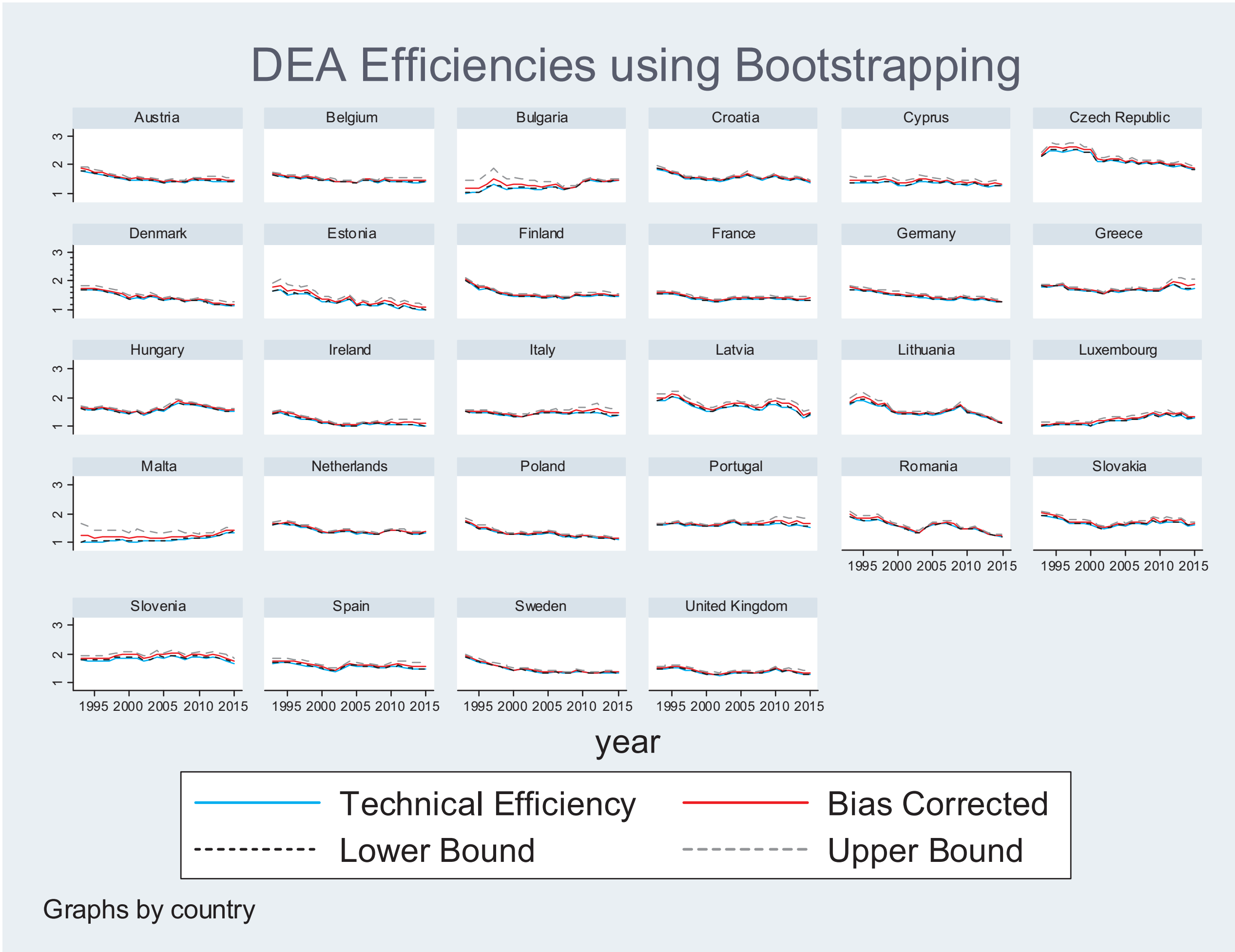

Fig. 1. DEA Efficiencies using Bootstraping (efficiencies on vertical axis and years on horizontal).

sustainable development, taking into consideration the impact of energy consumption (exhaustible resources) and environmental degradation (CO_2 emissions) is limited in terms of bias correction using the smoothed homogeneous bootstrap. Based on the literature, there is a lack of reliable test procedures for examining returns to scale in the context of non-parametric modelling of technical efficiency. As indicated by Simar and Wilson (2002) many studies using DEA and imposing an a priori restrictive assumption of CRS produce statistically inconsistent estimates when the true technology displays non-constant returns to scale. The determination of whether the underlying technology exhibits increasing, constant, or decreasing returns to scale is of great importance to any study of productive efficiency in formulating national economic and energy policies as it improves the applicability and credibility of the research results and can be suitably used for comparing the performance of DMUs in distinct periods.

According to the estimation procedures proposed by Simar and Wilson (2002), we aim to cover this gap and to provide more reliable and useful results for decision-makers contributing in addressing the lack in testing for returns to scale and adding to the limited empirical research. Specifically, radial technical efficiency measures are calculated (Fare, 1988; Fare and Lovell, 1994; Färe et al., 1994) aiming here to derive estimators of production frontiers that represent optimal combinations of inputs (labor, capital and energy) and outputs (GDP, CO_2 emissions). For this reason an order-α approach and consistent bootstrap procedures are used to take into consideration the sensitivity of distance functions and thus efficiency. Using DEA and in order to overcome the usual problems of specification and measurement errors our paper employs the advances of DEA as introduced by Daraio and Simar (2005, 2007a, 2007b) and Jeong et al. (2010) together with the inferential approach as proposed by Simar and Wilson (1998, 2000a, 2000b). This paper is an extension and improvement of work originally reported by Bampatsou and Halkos (2017).

After a brief review of the existing relative literature in Section 1, the remaining of this article is organized as follows. Section 2 presents the empirical methodology and the formulation of the proposed models. Section 3 contains the empirical findings. The final section concludes commenting on the derived results.

2. Data and methodology

For our purpose we use a data set of the EU 28 countries, for a period spanning from 1993 to 2015 in order to introduce the radial measure of non parametric frontier analysis. As inputs labor (number of persons engaged - in millions), capital (capital stock at current PPPs - in mil. 2011US$) and energy (total primary energy consumption - in quadrillion btu) are used while we utilize GDP (output-side real GDP at chained PPPs - in mil. 2011US$) as desirable and CO_2 emissions (total CO_2 emissions from the consumption of energy - in million metric tons) as undesirable outputs. The source for labor, capital and GDP data is the Penn World Table, version 9.0 (Feenstra et al., 2015) and for the energy and CO_2 emissions data the U.S. Energy Information Administration (EIA, 2018).

More specifically, we compute Radial (Debreu-Farrell) output-based measures of technical efficiency under the assumption of CRS, Non-