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Heterogeneous technologies, strategic groups and environmental efficiency technology gaps for European countries

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HIGHLIGHTS

- We estimate technology gaps (TGs) for 25 EU countries in two distinct periods.
- We estimate environmental efficiency technology gaps (EETGs).
- We consider countries' technological capabilities with R&D, innovation and eco-innovation.
- We test the effect of different frontier constitutions on TGs-EETGs.
- We denote the specific role of knowledge spillovers.

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ABSTRACT

This paper measures technology (TG) and environmental efficiency technology gaps (EETGs) in 25 European countries over two distinct periods 2002 and 2008 examining the possible effect of adopted environmental regulations and the Kyoto protocol commitments on environmental efficiency technology gaps. However, the introduction of the metafrontier in our analysis puts into our discussion the role of heterogeneous technologies and its effect on the above-mentioned measures. Employing a directional distance function, we investigate whether there is an actual difference, in terms of environmental efficiency and efficiency performance, among European countries considering the technological frontiers under which they operate. The construction of individual frontiers has been realized employing a large number of variables that are highly correlated with countries' learning and absorbing capacity, new technological knowledge and using economic theory and classical frontier discrimination like developed vs. developing, North vs. South and participation in the Eurozone or not. The overall results indicate a crucial role of heterogeneous technologies for technology gaps in both periods. Moreover, a significant decrease for both measures, although in different percent, has been recorded emphasizing the key role of knowledge spillovers.

1. Introduction and motivation

The Intergovernmental Panel on Climate Change (2007) has assessed that global warming has over the last 50 year been caused due to anthropogenic greenhouse gas emissions. The significance of this problem is apparent from cases such as the signing of Kyoto Agreement in 1997 and subsequent efforts in Copenhagen and Cancun (2010), Durban and Doha (2011) as well as Warsaw (2013) to reach an international agreement aiming at reducing greenhouse gas emissions. In the face of climate change repercussions, the European Union has devoted a large portion of its available resources towards designing and implementing mitigation towards achieving a satisfactory level of sustainable development (Commission Directive, 2012/27/EU; CEC, 2007, 2013).

The purpose of this paper is threefold. We firstly use the directional distance function (hereafter DDF) that incorporates both GDP as a desirable output and CO_2 emission as an undesirable output, so as to measure a countries' technical and environmental efficiency performance. The second factor taken into account in this paper is based on the assumption that the estimation of technology gaps for each country is interrelated with the relevant distance from their group. It is therefore worth noting that the constitution of group frontier is an essential factor which needs to be taken into account. The introduction of the metafrontier framework in this study provides the opportunity to estimate, the associated technological gaps relative to the metatechnology available in European countries.

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The traditional production theory (Fare and Grosskopf, 2004) connects technology sets with the existence of a frontier taking into account both input and output combinations as well as the number of decision making units (henceforth DMUs) which participate (Samoilenko and Osei-Bryson, 2010). The assumption for many studies in efficiency analysis is that DMUs are treated as a “homogeneous” group using the same production technology is under investigation by many authors (Samoilenko and Osei-Bryson, 2010; Haas and Murphy, 2003). We need to therefore note that the inclusion of non-homogeneous DMUs results in biased estimators. In line with this, the formation of technological frontiers based on available techniques and the examination of associated efficiency measures consists of the third purpose of this paper.

In order to address the above issues, the vast majority of studies have employed alternative techniques in order to determine appropriate DMUs which construct the frontier based mainly on cluster analysis (Dyson et al., 2001). Moreover, the introduction of the metafrontier as a common envelope has been used extensively in the literature denoting as a geographical clustering indicator in order to estimate countries' technology gap (Battese et al., 2004). Therefore, the adoption of a geographical indicator as an additional factor to be used when clustering is needed departs from the international trade paradigm (Krugman, 1997). This, in our point of view appears to be an inadequate indicator in some cases (Chiu et al., 2012). The main reason that is merely biased, concerns the technology level of each country a concept very closely related to the estimation of technological frontier formation.

A unique dataset, at the second stage, has been used with specific reference to the years 2002 and 2008 and consisting of variables that represent innovative, eco-innovative and R&D countries intensive activities during these two specific years. This specific dataset has been adopted to individually construct frontiers using the widely used technique of cluster analysis for grouping data and its extension concerning data mining and neural network hierarchical cluster analysis. The present study not only deals with efficiency evaluation at an individual and upper level but also proceeds to the calculation of environmental efficiency scores and the associated technological gaps. In addition, it implements an essential experiment concerning the construction of separate technological groups with respect to their technological characteristics. Given the aforementioned research background concerning technology heterogeneity, this study clearly tries to investigate latent intra-frontier heterogeneity arising from the different frontier construction.

In our analysis of the years 2002 and 2008 (post-Kyoto period) we examined 25 European countries. The selection of 2002 and 2008 was not arbitrarily chosen. These specific two years are highly correlated with the implementation of the Kyoto protocol and the adoption and commitment period performance, the implementation of strategic energy technology plans (SET), the introduction of European Emission Trading (Riccardi et al., 2012), the initiation of sustained investment in R&D, the institutionalizing of international agreements the operation of European Technology Platforms (ETPS) (Kanellakis et al., 2013) and the consequential, to an extent, effects of European and national environmental regulation implementation.[1] In addition, these specific years reflect, to a degree, the technological trajectories at both a national and a European level (Dosi, 1982). The results of our analysis reflect firstly the importance of different frontier formations and the consequential effect on technology and environmental efficiency gaps and secondly how European environmental and energy policies aiming to reduce energy consumption and greenhouse gases affect the environmental efficiency of these countries.

This paper is organized as follows: In Section 2 we introduce the concept of heterogeneous technologies and present the methodology adopted establishing the reference for the present research. In Section 3, data is presented while, Section 4 is devoted to presenting and discussing the results. Finally, Section 5 concludes.

2. Methodological issues

Many studies have been recorded incorporating directional distance functions in order to mostly measure energy and environmental performance of different DMUs.[2] Extending the directional distance function Zhang et al. (2013), Choi et al. (2012) and Fukuyama and Weber (2009) proposed a slacks-based efficiency measure of efficiency extending the DDF, while Zhou et al. (2012) use a non-radial DDF and Mahlberg and Sahoo (2011) a non-radial Luenberg indicator. In addition, Zaim and Taskin (2000) and Cuesta et al. (2009) developed a hyperbolic efficiency measure while Fukuyama et al. (2011) and Barros et al. (2012) incorporating directional distance functions proposed slack-based measures and weighted Russell DDF. Finally, Chang and Hu (2010), Fare and Grosskopf (2010) and Cheng and Zervopoulos (2014) developed a generalized non-radial DDF. In the present study we follow Chiu et al. (2012) and Yu-Ying Lin et al. (2013) to measure, not only technology gaps, but also environmental efficiency technology gaps exploiting the scarcity of similar studies under the presence of heterogeneity.

2.1. Handling heterogeneity in efficiency analysis

Performance of DMUs may differ widely even if, on a theoretical basis, they employ the same set of inputs and “identical” or similar production technology. Although the neoclassical theory of the firm does not deal with such differences, a vast body of recent literature provides evidence of this specific aspect of DMUs' heterogeneity (Samoilenko and Osei-Bryson, 2008, 2010) stating that all DMU's participating in the same frontier “behave” almost identically in the sense of receiving the same input–output mix. The above-mentioned assumption is also closely linked to the “homogeneity” assumption (Haas and Murphy, 2003) based on the logic that all DMUs are “alike” and directly comparable sharing the same technology set. Thus, the problem of the construction of a “homogeneous” frontier is real and undoubtedly exists. Since the frontiers are not being shaped by homogeneous DMUs, heterogeneity is always present making the benchmarking asymmetric and imperfect.

As there is no theoretical contribution in this issue, many authors proposed alternatives to circumvent the non-homogeneity of the DMUs (i.e. Dyson et al., 2001; Castelli et al., 2001; Haas and Murphy, 2003; Saen et al., 2005; Xiao and Li, 2007). Among the methodologies used to overcome this problem we can refer to generalized DEA CCR[3] model and applied interpolation methods to estimate missing values, analysis hierarchical process (AHP) method for measuring the relative weights of the DMUs, a chance-constrained DEA-type model to calculate the efficiency, cluster analysis and neural networks techniques (Samoilenko and Osei-Bryson, 2008).[4] Following this strand of literature we employ the

[1] We owe this to an anonymous referee.

[2] See Zhang et al. (2013), Riccardi et al. (2012) and Chiu et al. (2012) for an analytical representation.

[3] Refers to one of the most basic data envelopment analysis models, the CCR model, which was initially proposed by Charnes, Cooper and Rhodes in 1978 and it is characterized by their initials.

[4] The issue of grouping the DMUs into homogeneous groups can still be seen as a