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Methodological and Ideological Options

An intertemporal approach to measuring environmental performance with directional distance functions: Greenhouse gas emissions in the European Union

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A B S T R A C T

The impact of economic activity on the environment is a matter of growing concern for firm managers, policymakers, researchers and society as a whole. Building on previous work by Kortelainen (2008) [Dynamic environmental performance analysis: A Malmquist index approach. Ecological Economics 64, 701–715], we contribute an approach to assessing *intertemporal environmental performance* at the level of the management of specific pollutants, as the result of *change in eco-efficiency* and *environmental technical change*, which identify catching-up with best available environmental practices and eco-innovation, respectively. In doing so, we use Data Envelopment Analysis techniques, directional distance functions and Luenberger productivity indicators. Our approach is employed to assess environmental performance in the emission of greenhouse gases in the European Union-28 over the period 1990–2011. The main result is that environmental performance has been boosted by *environmental technical change* rather than by increases in eco-efficiency, although with certain differences among air pollutants. Accordingly, policy measures aimed at enhancing eco-efficiency are recommended to improve environmental performance in European countries regarding greenhouse gas emissions.

1. Introduction

Economic performance is a recurrent matter of study in both theoretical and empirical economics; as a result of this interest, many researchers have addressed the issue of assessing performance using a wide range of measures of efficiency and productivity growth (see Balk, 2008). In parallel, the traditional view of economic growth entirely focused on increasing the quantity of goods and services available to satisfy human needs has given way in recent decades to a vision of growth based on *sustainable development*, understood as the 'development that meets the needs of the present without compromising the ability of future generations to meet their own needs' (WCED, 1987, p.43). *Sustainability* is a multifaceted concept that involves, at least, two strongly related dimensions, namely, the economic dimension and the environmental dimension. Furthermore, literature in the field of ecological economics has long recognised the need to develop tools to assess the impact of productive activity on the environment, as a necessary condition for environmental policies aimed at achieving sustainable development to be effective (Huppes and Ishikawa, 2005a, 2009).

A strand of literature has approached the analysis of sustainability through the concept of *eco-efficiency* that, according to the OECD (1998, p.7), '…expresses the efficiency with which ecological resources are used to meet human needs (…) and can also be defined as a ratio of output and input so that the output represents the value of the products or services that a company produces and the input is the sum of environmental pressures caused by the production'. Eco-efficiency can be interpreted then as a relationship between economic performance, measured by the value of products and services produced, and an aggregate measure of environmental performance (see Schaltegger and Synnestvedt, 2002).[1] Moreover, several international organisations have recognised that the assessment of eco-efficiency is a powerful instrument capable of providing managers and policymakers with

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[1] This definition of eco-efficiency has the advantage of easiness of computation and straightforwardness of interpretation for policymakers and the general public. However, other definitions can also be found in this literature, e.g., taking production factors (labour and capital) and environmental pollution simultaneously into account (see Korhonen and Luptacik, 2004).

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helpful information to design better managerial strategies and environmental policies (United Nations, 2009).

In this line of research, Kuosmanen and Kortelainen (2005) developed a general framework to measure *relative eco-efficiency* using Data Envelopment Analysis (DEA) techniques (Charnes et al., 1978). Based on the *benefit of the doubt* principle (Cherchye et al., 2007), DEA allows building an aggregate score of environmental performance without resorting to prices, which is a noticeable advantage for the purpose of assessing eco-efficiency in that pollutants and environmental pressures have no market prices. Later on, Kortelainen (2008) generalised this approach to an intertemporal setting using Malmquist indices (Malmquist, 1953) and conventional Shephard's distance functions (Shephard, 1970) to develop an overall proportional measure of *dynamic environmental performance*. In the spirit of the seminal paper by Färe et al. (1994), *environmental performance change* was decomposed into the result of *relative eco-efficiency change* and *environmental technical change*, as a natural way to identify, respectively, catching-up with best available environmental practices and eco-innovation or progress in environmental technology.

Our paper extends the approach by Kortelainen (2008) to assessing *intertemporal environmental performance*[2] and its determinants at the level of the management of specific pollutants. In doing so, we use Luenberger productivity indicators (Chambers et al., 1996), directional distance functions (Färe and Grosskopf, 2000) and the DEA-based approach to eco-efficiency measurement by Picazo-Tadeo et al. (2012). Our foremost contribution to the state-of-the-art in this literature, and particularly to the two aforementioned papers, is that we propose different indicators of environmental performance growth, eco-efficiency growth and *environmental technical change*, representing different sets of preferences regarding economic and ecological performance. This methodological approach is employed to assess *intertemporal environmental performance* in greenhouse gas (GHG) emissions in the European Union-28 (EU-28) over the period 1990–2011.

Global warming and climate change caused by rising concentrations of GHG are a matter of increasing concern for policymakers, researchers and society around the world. Furthermore, several studies have addressed the analysis of environmental performance in the European Union (EU) regarding GHG emissions, in an attempt to provide scientific grounds to European environmental policies against climate change. Without aiming to be exhaustive, Mahlberg et al. (2011) employed Malmquist indices to analyse the driving forces of eco-productivity change in 14 EU member countries for the period 1995–2004, using aggregate GHG emissions to account for the impact of economic activity on the environment. The foremost result is that eco-productivity growth was more driven by reduction in GHG emissions than by input savings. Camarero et al. (in press) assessed convergence in eco-efficiency during the period 1990–2009 in the European Union-27 (EU-27) regarding aggregate GHG emissions as well as individual emissions of carbon dioxide, nitrous oxide and methane. Although specific convergence clubs were found for different pollutants, four groups of countries can roughly be defined: the first two include core EU high-income countries, a third club is mainly made up of peripheral countries, and a final group involves most Eastern European countries. Accordingly, the authors suggest that different environmental policies might be required for countries showing different eco-efficiency convergence paths.

The contribution of our paper to existing empirical studies on environmental performance regarding GHG emissions, and particularly to those based in the use of DEA techniques, is that we provide an assessment of the environmental performance of EU members and its determinants at the level of the management of particular contaminant gases. Furthermore, beyond the assessment of convergence in eco-efficiency as regards specific GHG emissions carried out by Camarero et al. (in press), we assess *intertemporal environmental performance* and its determinants, including *environmental technical change* and change in eco-efficiency. In our opinion, these empirical contributions might provide European policymakers with sound information to improve the design of their environmental policies.

Following this Introduction, Section 2 develops the methodology. Section 3 describes the data and the empirical application. Section 4 discusses the results and highlights some policy recommendations, while Section 5 concludes and suggests some avenues for future research.

2. Methodology

2.1. Environmental Performance, Eco-efficiency and Environmental Technical Change

Let us start by assuming that we observe a set of $k = 1,\ldots,K$ producers to which we will refer as decision-making units (DMUs) hereafter, which each year from a period $t = 1,\ldots,T$ generate an economic result represented by value added v^t, and a series of $n = 1,\ldots,N$ pollutants that damage the environment denoted by the vector $\mathbf{p}^t = (p_1^t, \ldots, p_N^t)$.[3]

The Pollutant Generating Technology Set (PGTS), which represents all feasible combinations of value added and pollutants in period t, is defined as (Kuosmanen and Kortelainen, 2005; also see Picazo-Tadeo et al., 2011):

$$PGTS^t = \left[\left(v^t, \mathbf{p}^t\right) \in R_+^{N+1} \middle| \text{value added } v^t \text{ can be obtained with pollutants } \mathbf{p}^t\right] \quad (1)$$

Environmental technology can also be represented by the Pollutant Requirement Set (PRS) (see Beltrán-Esteve et al., 2014), which represents all the combinations of pollutants **p** that permit obtaining at least value added v, and which in period t is defined as:

$$PRS^t\left(v^t\right) = \left[\mathbf{p}^t \middle| \left(v^t, \mathbf{p}^t\right) \in PGTS^t\right] \quad (2)$$

Following Picazo-Tadeo et al. (2012), we assume that environmental technology has the following properties: a) economic activity unavoidably dumps some pollutants on the environment, and the only way not to generate pollutants is not to produce; b) lower value added can always be obtained dumping the same amount of pollutants on the environment; c) pollutants can always be increased for any given value added; and, finally, d) any convex combination of feasible (observed) pairs of value added and pollutants is also feasible. In accordance with earlier papers by Korhonen and Luptacik (2004), Kuosmanen and Kortelainen (2005) and Zhang et al. (2008), in this characterisation of the technology pollutants are formally treated as conventional inputs.[4]

Let us now define *environmental performance* as the ratio between economic value added and a composite indicator of the aggregate pollutant dumped on the environment (see Kortelainen, 2008). Accordingly, environmental performance would improve when the value

[2] By using the expression *intertemporal environmental performance* we depart from the terminology employed by Kortelainen (2008), who refers to his measure of performance as a *dynamic environmental performance* indicator. The reason is that this approach does not model the dynamics of the change in environmental performance, but just compares scores of performance observed at different points of time.

[3] Vectors are in bold type throughout the paper to distinguish them from scalars.

[4] Undesirable resultants of production processes are often considered as *bad* outputs that generate environmental pressures, as it is the case with climate changing emissions, which might have not only contemporary impacts on economy and society but also in later periods. Dyckhoff and Allen (2001) discuss different approaches to treating *undesirables* in the framework of DEA-based models.