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Assessing environmental performance in the European Union: Eco-innovation *versus* catching-up

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ABSTRACT

This paper assesses environmental performance in the European Union (EU) using Luenberger productivity indicators, directional distance functions and *Data Envelopment Analysis* techniques. It considers four indicators of the pressures exerted by economic activity on the environment: global warming, tropospheric ozone formation, acidification and particulate formation. The change in environmental performance from the early 2000s onwards is decomposed at the levels of country and environmental pressure, and as the result of eco-innovations and catching-up with the best available environmental technologies; furthermore, we distinguish between the periods of economic growth (2001–07) and severe crisis (2007–13). Our main finding is that environmental performance improved in both periods, mainly fuelled by advances in environmental technology. Accordingly, environmental policies aimed at boosting catching-up are highly recommended, particularly in the newer member states that joined the EU from 2004 onwards, which perform further away from their respective environmental technological frontiers. In addition, re-establishing the pre-crisis eco-innovation investment levels would also be highly advisable in order to return to the rates of environmental technical progress registered in the expansion period.

1. Introduction

The *Europe 2020 Strategy* was set forth by the European Commission in March 2010 (EC, 2010a) as a strategy for smart, sustainable and inclusive economic growth in the European Union (EU) through to 2020. Five headline targets were agreed to in order for the EU to be able to meet this deadline, consisting of employment, research and development, climate change and energy sustainability, education, and social inclusion and poverty. Regarding climate change and green growth, key aspects of the strategy are resource efficiency and better management of natural resources as part of efforts to decouple economic growth from the use of resources and support the shift towards a low-carbon economy. These eco-friendly goals were summed up in the so-called *20/20/20 target* that included a 20% reduction in greenhouse gas emissions compared to 1990 levels (or 30% if the conditions were favourable), a 20% share of energy from renewable sources, and a 20% increase in energy efficiency. Furthermore, concrete actions conducive to accomplishing these objectives should be integrated into environmental and energy policies at both EU and national levels.[1]

In this regard, several institutions and international organisations have recognised that effective environmental and energy policies should be based on evidence from robust environmental indicators, combining both ecological and economic issues. The United Nations acknowledges that '*Making the concept of green growth operational for public policies requires a measurement that would capture the pattern of the quality of economic growth over time… Without indicators or a conceptual framework to guide policymakers, green growth as a paradigm shift in policymaking would prove an elusive goal.*' (UN, 2009; p.3). Moreover, the European Environment Agency recently pointed out that '*Environmental indicators are essential tools for assessing environmental trends, tracking progress against objectives and targets, evaluating the effectiveness of policies and communicating complex phenomena to non-technical audiences.*' (EEA, 2014; p.5).

As a result of the increasing interest of society and politicians in sustainable growth, a burgeoning scientific literature has emerged in the last few decades that studies the relationship between the production of goods and services and the environment. Grounded in the field of efficiency and productivity analyses, a branch of

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[1] Jänicke (2012) reviews other international programs for green growth, including the OECD's *Green Growth Strategy* (OECD, 2011a), the UN's *Environment Programme* (UNEP, 2011), and the sustainability programme *Towards a Sustainable Asia* (AASA, 2011).

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research has focused on evaluating environmental performance. Since the environmental productivity indicator proposed by Pittman (1983), a growing literature devoted to developing indicators of environmental performance has emerged; while Tyteca (1996) reviewed the first contributions, in the 2000s several papers further contributed to this field of research. Without aiming to be exhaustive, Kuosmanen and Kortelainen (2005) proposed a static framework to assess eco-efficiency using *Data Envelopment Analysis* (DEA) techniques, which Kortelainen (2008) then added to by assessing environmental performance in a dynamic setting using Malmquist productivity indices (Malmquist, 1953) and conventional Shephard's distance functions (Shephard, 1970). Later, Picazo-Tadeo et al. (2014) (see also Azad and Ancev, 2014) adapted this approach to assess environmental performance at the level of the management of specific pollutants.

In this research paper, we assess environmental performance in the EU using Luenberger productivity indicators (Chambers et al., 1996), directional distance functions (DDFs) (Färe and Grosskopf, 2000) and DEA techniques (Charnes et al., 1978). This approach enables an assessment of the change in *environmental performance* at the country and environmental-pressure levels between 2001 and 2013 as the result of *environmental technical change* and *environmental efficiency change*. While the former measures the progress in the environmental technology brought about by eco-innovations, the latter assesses catching-up with best available environmental technologies.

A number of papers have analysed environmental performance in the EU from different angles; they include Kortelainen (2008), Oh (2010), Mahlberg and Sahoo (2011), Camarero et al. (2014), Picazo-Tadeo et al. (2014) and Gómez-Calvet et al. (2016), among others. Our contribution to this literature is twofold. Going beyond the paper by Picazo-Tadeo et al. (2014), which analyses environmental performance in the emission of greenhouse gases, we consider a much richer array of 12 contaminants that are aggregated into environmental pressures representing concerns for society. Furthermore, in addition to a global or proportional environmental performance indicator in line with Kortelainen (2008), we also assess environmental performance in the management of particular environmental pressures. Moreover, more European countries are included in our analysis, and we also use an environmental productivity approach by including conventional inputs. Lastly, we contribute separate analyses of environmental performance change and its determinants for the period of economic expansion (2001–07), and the period of severe economic crisis worldwide (2007–13). Performance is also separately analysed for the group of European countries in the former European Union-15 (EU-15), and the group of recent member states that joined the EU from 2004 onwards.

The remainder of the paper is organised as follows. Section 2 outlines the main features of the methodology and describes the data and variables. The results are presented and discussed in Section 3, while Section 4 concludes and highlights a number of policy recommendations.

2. Methodological issues, dataset and variables

2.1. Methodological issues

As mentioned in the Introduction, our approach to assessing environmental performance is based in the use of Luenberger productivity indicators, DDFs and DEA techniques. In order to explain this methodology, let us start by assuming a general technology that in period t transforms a vector of n=1,…,N inputs $x^t \in \Re_+^N$ into a vector of m=1,…,M outputs $y^t \in \Re_+^M$, and is defined as:

$$T^t = \left[(x^t, y^t) \;\mid x^t \text{ can produce } y^t\right] \tag{1}$$

It is also assumed that this technology satisfies certain conventional axioms, including the possibility of inactivity, no free lunch, free disposability of inputs and outputs, and convexity (see Grosskopf, 1986 and Färe and Primont, 1995 for a discussion on these axioms). Furthermore, let us assume that producing outputs also generates a set of h=1,…,H pressures on the environment $p^t \in \Re_+^H$, which are formally treated as free disposable inputs. Therefore, for the purpose of our approach, the vector of inputs in the definition of the technology can be formally expressed as (x^t, p^t), where x^t stands for conventional inputs and p^t for environmental pressures.

In the field of modelling environmental performance with DEA,[2] undesirable resultants of economic activity have frequently been treated as inputs into production processes (see, among others, Hailu and Veeman, 2001; Dyckhoff and Allen, 2001; Lee et al., 2002; Korhonen and Luptacik, 2004; Kuosmanen and Kortelainen, 2005; Zhang et al., 2008; Yang and Pollitt, 2009; Picazo-Tadeo et al., 2014; Beltrán-Esteve and Picazo-Tadeo, 2015). One convincing reason behind this consideration is that environmentally detrimental resultants from economic activity can be regarded as the use of the environmental capacity required for their disposal (Considine and Larson, 2006); in other words, considering emissions as inputs is a way of accounting for the use of natural resources (Cropper and Oates, 1992). Furthermore, Mahlberg and Sahoo (2011; p.724) provide a persuasive economic argument in favour of treating *undesirables* as inputs, asserting that '*… both inputs and undesirable outputs incur costs for a firm because it requires the diversion of productive inputs from the production of desirable (good) outputs for abatement purposes in compliance with the environmental regulations; and hence, firms are usually interested in decreasing both types of variables as much as possible*'.[3]

Using DEA techniques,[4] and considering that we observe a set of c=1,…,C decision making units (DMUs), the *environmental technology* can be approximated as:

$$T_{DEA}^t = \left[(x^t, p^t, y^t) \;\middle|\; \begin{array}{l} \sum_{c=1}^{C} z_c x_{nc}^t \le x_n^t, \quad \forall\, n; \quad \sum_{c=1}^{C} z_c p_{hc}^t \le p_h^t, \quad \forall\, h; \\ \sum_{c=1}^{C} z_c y_{mc}^t \ge y_m^t, \quad \forall\, m; \quad z_c \ge 0, \quad \forall\, c \end{array}\right] \tag{2}$$

In this expression, z_c stands for the elements of the so-called intensities vector that allows the formation of linear combinations of outputs, conventional inputs and environmental pressures of observed

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[2] In a recent paper, Dakpo et al. (2016) review the different approaches to modelling pollution-generating technologies followed in performance benchmarking studies, highlighting their main advantages and drawbacks. Other interesting papers offering a similar review are Seiford and Zhu (2002), Førsund (2009) and Murty et al. (2012).

[3] Modelling undesirable resultants from economic activity in performance analyses is, however, an issue that after three decades of research remains open to academic debate. The consideration of emissions as inputs has often been criticised for not reflecting the true production process (Seiford and Zhu, 2002); criticisms also come from a physical perspective (Färe and Grosskopf, 2003; Podinovski and Kuosmanen, 2011), and based on the material balance principle (Ayres, 1995). Nevertheless, Førsund (2009; p.10) argued that '*… when a defence of the procedure is offered* [in reference to treating emissions as inputs], *the most satisfactory position may be in a macro setting* [as we do in our research]'. Alternatively, another strand of literature has modelled emissions as undesirable outputs of production processes, under the weak disposability and joint production axioms (see Färe et al., 1986; Färe et al., 1989; Färe and Grosskopf, 2009). However, this approach is not free of criticism either (Dakpo et al., 2016; p.351–52 presents the main limitations of the weak disposability axiom in modelling pollution-generating technologies). In this respect, it has been pointed out that this procedure does not comply with the laws of thermodynamics (Ebert and Welsch, 2007) or the material balance principle (Murty et al., 2012). It has also been argued that, in practice, the weak disposability axiom treats pollutants as neutrals rather than as inputs or outputs (Hailu and Veeman, 2001). Furthermore, negative shadow prices for pollutants might be obtained and several problems may also occur when estimating performance with the weak disposability axiom (Picazo-Tadeo and Prior, 2009; Chen, 2014).

[4] DEA is a widespread non-parametric approach to the evaluation of performance, initially proposed by Charnes et al. (1978), which has been used in hundreds of empirical papers (see Cook and Seiford, 2009, for a review; Sueyoshi et al., 2017 reviews the DEA literature applied to energy and environment). Readers are referred to Cooper et al. (2007) for technical details on this technique.