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A new frontier approach to model the eco-efficiency in European countries

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A B S T R A C T

This study aims to evaluate the resource and environment efficiency problem of European countries. We specify a new stochastic frontier model where Gross Domestic Product (GDP) is considered as the desirable output and Greenhouse Gases (GHG) emissions as the undesirable output. Capital, Labor, Fossil fuels and Renewable Energy consumption are regarded as inputs. GDP/GHG ratio is maximized given the values of the other four variables. The study is divided into two distinct periods: 2000–2004 and 2005–2011. This division is related to the implementation of the Kyoto Protocol in 2005, and will allow us to evaluate the difference between the levels of efficiency before and after the establishment of environmental targets. Since stochastic frontier models are typically ill-posed, a new maximum entropy approach to assess technical efficiency, which combines information from the data envelopment analysis and the structure of composed error from the stochastic frontier approach without requiring distributional assumptions, is presented in this work.

1. Introduction

Economic activities use production factors as energy resources, labor and capital to produce desirable goods and services, but simultaneously produce undesirable outputs, such as Greenhouse Gases (GHG), and particularly, Carbon Dioxide (CO_2) emissions. According to the IPCC report (2007), the energy consumption of fossil fuels such as coal, oil and natural gas is the major contributor towards the increase of GHG emissions including CO_2. Thus, if the energy is used inefficiently, this will lead to higher emission levels. It becomes necessary to base the economic, the energy and the environmental policies on the efficient use of resources, in particular on energy efficiency.

But environmental efficiency cannot be separated from economic efficiency. Both help to ensure the competitiveness of a country's economy as well as its environmental sustainability and energy security. In addition, the full range of environmental issues and globalization of economies means that policies are increasingly global. Furthermore, for policymaking it is necessary to have indicators in this context, that is, indicators of economic and environmental efficiency, which compare the evolution of countries or sectors, set goals and implement effective policies, either globally or locally.

Economic efficiency can be divided in technical efficiency (which reflects the ability of a production unit to obtain maximal output from a given set of inputs and the production technology) and allocative efficiency (which reflects the ability of a production unit to use the inputs in optimal proportions given their prices and the production technology).

Economic efficiency does not imply environmental efficiency, as the production processes may rely too much on fossil fuels or technologies, which although technically efficient, and cheap, lead to high levels of emissions or other environmental impacts. But if there is technical or economic inefficiency, it can cause environmental inefficiency. For example, waste of raw materials, or inefficient use of energy leads to a technical, economic and environmental inefficiency also because we are wasting resources and increasing pollution.

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The study of economic and environmental efficiency, at the macroeconomic level for several European countries, is of great relevance to reveal how has been the path in this field, but also to inform policy makers about the economic environmental efficiency of their countries and if there is need to amend or introduce new policies. Blühdorn and Welsh (2007) suggest that we are in a new era and that ecopolitics needs a new environmental sociology. They pose an important question, at the same time that call ecopolitics the politics of unsustainability: “How do advanced modern capitalist consumer democracies try and manage to sustain what is known to be unsustainable?”

Technological optimists believe that innovation is a key to produce more with less. Progress would be enough to generate the decoupling of economic growth and impact on nature (Lovins, 1998, 2011; Lomborg, 2001). In other words, it would be possible to obtain economic growth and at the same time reduce our absolute demand for natural resources. In another line are technological pessimists that say that in the context of a much more dynamic and populous world, technology alone is not enough to solve all the challenges (Alexander, 2014). So in the future, countries will need to develop without economic growth: the so-called “steady state”. GDP may not be the barometer for measuring the health and well-being of economies.

The study of eco-efficiency, joining the economic and environmental parameters together, may respond, or at least illuminate the readers about the sustainability of these theories.

There are several ways to measure the so-called Eco-Efficiency (EE), which depend on the purpose and scope of the study. Wursthorn et al. (2011) argues that “there is an intensive discussion and widespread research on eco-efficiency, which are concerned with different scopes and scales (see for example the special issue of Ecological Economics 2009, volume 68, issue 6)”.

As defined by the World Business Council for Sustainable Development (WBCSD), “eco-efficiency is achieved by the delivery of competitively priced goods and services that satisfy human needs and bring quality of life, while progressively reducing ecological impacts and resource intensity throughout the life-cycle to a level at least in line with the Earth's estimated carrying capacity”. The concept is concerned with creating more value with less impact (www.wbcsd.org).

In the same line of thought, ISO 14045 defines eco-efficiency as a quantitative tool for management, which allows studying the environmental impacts of a product throughout its life cycle (Life Cycle Assessment (LCA)), as recommended by previous ISO 14040 and ISO 14044. Thus, EE has three goals: to increase the value of the service or good, to optimize the use of resources, and to reduce the environmental impact. LCA is used at product or enterprise level. At national level it will be more complex and cumbersome to apply it.

Other definitions of EE can be pointed, as “the efficiency with which ecological resources are used to meet human needs”, by OECD (1998) or “the ability of firms, industries or economies to produce goods and services while incurring less impact on the environment and consuming fewer natural resources” by Picazo-Tadeo et al. (2011).

The simplest indicator of EE relates the economic output or Gross Domestic Product (GDP) with the environmental impact caused by the production process, for instance, the ratio GDP/CO_2. As the production process may give rise to other environmental impacts, other measures, that replace CO_2 by a composite good of environmental pressures, have emerged (Schmidheiny and Zorraquin, 1996).

This study aims to evaluate the resource and environment efficiency (eco-efficiency) problem of European countries. We specify a new stochastic frontier model where GDP is considered as the desirable output and GHG emissions as the undesirable output. We use the ratio between GDP and GHG emissions as definition of EE. Fossil fuel consumption, Renewable Energy Consumption, Capital and Labor are regarded as inputs. GDP by GHG emissions ratio is maximized given the values of the other three variables. EE will be greater when the emissions decrease to the same value of GDP, when production is greater for the same amount of emissions, or simultaneously when production increases and GHG emissions shrink.

The study is divided into two distinct periods: 2000–2004 and 2005–2011. This division is related to the implementation of the Kyoto Protocol in 2005, and will allow us to evaluate the difference between the levels of eco-efficiency before and after the establishment of environmental targets.

Since stochastic frontier models are typically ill-posed, many researchers claim the urgent need to develop robust estimation techniques. Recently, maximum entropy estimators have been used in the literature as powerful alternatives to traditional estimators in the estimation of stochastic frontier models. In this study, a stochastic frontier approach using some maximum entropy estimators is proposed as an alternative to the Kaya identity. A new maximum entropy approach to assess technical efficiency, which combines information from the data envelopment analysis (DEA) and the structure of composed error from the stochastic frontier analysis (SFA) without requiring distributional assumptions, is presented in this work.

In this work technical efficiency was estimated, but as the maximized output is the GDP/GHG ratio, the estimation of technical efficiency is also a measure of eco-efficiency.

The article is made up of five sections, including this introduction. Section 2 summarizes the literature that study EE, namely with DEA technique. Section 3 presents data and methodology. Section 4 presents the main results and discussion and Section 5 summarizes the conclusions.

2. Literature review

The use of benchmarking and activity analysis or DEA techniques have emerged in recent years as more sophisticated techniques to assess the EE of the countries and/or economic sectors. Several studies have considered the existence of desirable and undesirable outputs of production, in which the environmental effects are seen as undesirable (Färe et al., 1989, 1996, 2004; Chung et al., 1997; Tyteca, 1996, 1997; Zofio and Prieto, 2001; Zhou et al., 2006, 2007). For example, Haynes et al. (1993) use DEA methodology to measure technical efficiency in pollution prevention activities, using chemical as input and chemical waste as output, along with other traditional inputs and outputs.

Some authors study sectoral EE, such as Picazo-Tadeo et al. (2011, 2012), who estimated EE for individual environmental pressures on the agricultural sector. Picazo-Tadeo and Prior (2009) used Directional Distance Functions and DEA to show that technologies where the biggest output producer is not the greatest polluter and those economic activities can diminish environmental damages without compromising the maximization of their output. These authors also made an application to Spanish ceramic tile producers. Mandal (2010) studied EE of the cement industry in India while Barba-Gutiérrez et al. (2009) used the Life Cycle Assessment to compare the EE of different household electric appliances using their environmental impact. Kortelainen and Kuosmanen (2005) analyzed four types of environmental pressures, through the EE analysis of road transport in Finland. Egilmez et al. (2013) applied Economic Input–Output Life Cycle Assessment (EIO-LCA) and DEA, for measuring the eco-efficiency in US manufacturing sectors. Avadí et al. (2014) used the combined LCA + DEA method for examining the eco-efficiency in 13 different fleet segments of fishing vessels, aggregated based on hull capacity of the vessels. Zhu et al. (2014)

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