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A non-parametric bootstrap-data envelopment analysis approach for environmental policy planning and management of agricultural efficiency in EU countries

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ABSTRACT

Globally, agriculture is a dominant form of human use of land with agro-ecosystems covering about 40% of the terrestrial surface of the Earth. In this context, the European Union considers agriculture a key sector of the economy, recognizing, however, the related environmental implications. The aim of this paper is to examine the agricultural efficiency of EU countries, through a bootstrap-Data Envelopment Analysis (DEA) approach, an effective nonparametric method for evaluating the relative efficiency of the decision-making units. European datasets, suitable for policies and focused on the integration between agricultural productivity and ecosystem services (ESs) conservation, have been used to support planners and managers. Data related to five inputs (labor, land, capital, fertilizers, and irrigation area) and to one output connected to the economic value of agricultural production were collected from 1993 to 2013. The results show that the majority of EU countries have been experiencing increasing or decreasing returns to scale, highlighting their potential to increase their production efficiency by modifying their input use. Both for the output-oriented approach and the input-oriented approach, the majority of EU countries could better rationalize their input use obtaining more outputs and achieving production efficiency. DEA, a non-parametric methodology has been applied, using the concept of a reference group of efficient decision-making units that produce a similar output (peer group). Input-oriented and output-oriented DEA results and comparison indicate that most of the oldest EU countries have a more efficient and optimized crop production process in terms of resource savings and output maximization. This is probably due to the application of the Common Agricultural Policy. Therefore, in policy planning but also in management decisions, attention should always be paid not only to the maximization of agricultural production, but also to the environmental resource overexploitation. In this sense, best agricultural practices could represent a model to follow because they can maintain ESs without depressing production by using practices like conservation tillage, crop diversification, legume intensification and biological control perform giving the same results as intensive, high-input systems.

1. Introduction

The fundamental global role played by agriculture in terms of environmental conservation, economic development, and social support to nutrition of the ever-growing world population, has made it a field of research interest (Pang et al., 2016). Given the fact that food accessibility represents one of the main factors supporting human welfare and quality of life (MEA, 2005), the stability of agricultural production, expressed in terms of crop yield and cultivated area, is of scientific and practical relevance (Garibaldi et al., 2011).

Agriculture is a dominant form of human land use globally, and agro-ecosystems cover about 40% of the terrestrial surface of the Earth (Power, 2010). In this context, the European Union considers agriculture a key sector of the economy, recognizing, however, the related environmental implications. Being a sector in a continuous phase of structural changes and affecting efficiency and productivity growth significantly, agriculture still draws the dominant interest of European institutions in terms of sustainable management and efficiency of natural resources use. Therefore, measuring environmental and economic efficiency provides policy-makers with valuable information for designing policies focused on regional sustainable development (Picazo-Tadeo et al., 2011).

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In terms of sustainable development, it is important to recognize that ecological systems both contribute to and are affected by the production of goods and services, called ecosystem services (ESs), which are of value to people. Among the four categories of ESs, food in terms of agricultural products is part of the provisioning services with a direct economic use-value associated to human use (MEA, 2005; Krutilla and Fisher, 1975). As highlighted by Dale and Polasky (2007), agriculture can affect and be affected by ESs through synergies and trade-offs, or by services and disservices (Zhang et al., 2007).

The aim of this paper is to examine the agricultural efficiency of EU countries, through a bootstrap-Data Envelopment Analysis (DEA) approach and the use of datasets suitable for policies, focused on the integration between agricultural productivity and ESs conservation, in order to develop a support tool for planners and managers.

In this paper, firstly, the general problem of trade-off between agricultural productivity and the maintenance of ES provision is presented as well as a comprehensive literature review of studies on agricultural efficiency based on the use of DEA. Afterwards, the methodology developed in this research is described with an overview of the model variables. Finally, the results are discussed, focusing on some insights for the optimization of agricultural production in the EU Countries in the light of the conservation of ESs.

1.1. *The relation between agriculture and ecosystem services: synergies and trade-offs*

Modern agriculture can be seen as a Green Revolution that has simplified traditional agro-ecosystems and replaced biological functions with increased external inputs of energy and agrochemicals (Bommarco et al., 2013). Agricultural intensification usually assures that the increasing global food demands are met, because it raises the productivity per unit area. However, it can have significant negative impacts on the environment and ESs (Tilman et al., 2001; Moss, 2008; Potts et al., 2010; Matson, 1997), or even negative effects on sustained crop productivity (Matson, 1997; Dale and Polasky, 2007). As a consequence, agriculture and other environmental threats, such as climate change, pollution, and biotic invasions have eroded many ESs sustaining human well-being (MEA, 2005). Agriculture and ESs are interrelated in at least three ways (Dale and Polasky, 2007): (1) agro-ecosystems generate beneficial ESs such as fertile soil production and retention, food production, and aesthetics; (2) agro-ecosystems receive beneficial ESs from other ecosystems such as pollination from surrounding non-agricultural ecosystems; and (3) ESs from non-agricultural systems may be impacted by agricultural practices.

Although agro-ecosystems may have low ES values per unit area when compared with other ecosystems, such as estuaries and wetlands (Costanza et al., 1997), they offer the best chance of increasing global ESs via definitions of appropriate goals for agriculture and the use of land-management regimes that favor ES provision. Therefore, as highlighted by Porter et al. (2009), agriculture can be seen as the largest ecological experiment on Earth, with a large potential to damage global ESs but also to promote them via ecologically informed approaches to the design of agro-ecosystems that value both marketed and non-marketed ESs. In this context, Bommarco et al. (2013) have proposed ecological intensification as an alternative to agricultural intensification, in order to make agriculture more productive, stable, and resilient while minimizing environmental impacts (Foley et al., 2005) and consisting in integrating the management of ESs into crop production systems.

1.2. *Literature review on the DEA method*

1.2.1. *The data envelopment analysis (DEA) method*

Assessing efficiency for different levels of territoriality and economic sectors has relevant practical implications, and thus, efficiency has become an essential research field. The classic paradigm defines productivity as the ratio between an output and the inputs used to achieve it (Daraio and Simar, 2007). Similarly, according to Lovell (1993), the productivity of a unit is the ratio of its outputs to its inputs, as well as in the efficiency literature where many authors conceptualize both productivity and efficiency as the ratio between outputs and inputs, without underlying any difference between the two concepts (Sengupta, 1995; Cooper et al., 2007).

Efficiency can be better defined as a distance between a certain quantity of input and output, and the quantity of input and output that defines the best possible frontier for a unit in its cluster. However, efficiency and productivity are complementary concepts. Measures of efficiency are more accurate than measures of productivity, because the former are compared with the most efficient frontier, by integrating the information included in productivity measures (Daraio and Simar, 2007).

The theme of productive efficiency has been analyzed since Adam Smith's pin factory and even before. However, a rigorous analytical approach applied to the measurement of efficiency in production originated only with the theoretical approach of Koopmans (1951) and Debreu (1951), empirically applied by Farrell (1957). International literature contains a large number of surveys and case studies dealing with efficiency, which represents the key factor to reach the global target of sustainable development (Song et al., 2012).

The two main approaches to measure efficiency are parametric and non-parametric, and in most cases, both methods achieve highly correlated results (Wadud and White, 2000; Thiam et al., 2001; Alene and Zeller, 2005). In this context, DEA is an effective non-parametric method for evaluating the relative efficiency of the decision-making units (DMUs), which does not need the exact functional form between inputs and outputs, overcoming some disadvantages of the parametric approach.

Due to their advantages DEA methods have been constantly applied to the agricultural sector. The first model proposed in scientific literature considered an input orientation and constant returns to scale (CRS) assumption (Charnes et al., 1978). In order to account for variable returns to scale (VRS) conditions, Banker et al. (1984) went beyond the CRS DEA model. In fact, biased technical efficiency (TE) values can be generated by adopting the CRS assumption, due to scale efficiencies (SE) that occur when not all DMUs are operating on the optimal scale (Coelli et al., 2005). The main limitation is that, since it is based on a deterministic model, it does not take into account the uncertainty characterizing the real world (so-called stochastic error). In fact, the classical DEA technique does not allow for the construction of confidence intervals, nor for the carrying out of tests on the estimated values (Seiford and Thrall, 1990). In order to overcome the limitation of the construction of confidence intervals, Simar and Wilson (2000a, 2000b) suggested to adopt a bootstrap DEA method, which allows to validate the results by obtaining confidence intervals and adjusted efficiency scores.

1.2.2. *DEA applied to agricultural studies*

As highlighted by the literature review of DEA application to agriculture (Table 1), there is a lack of studies evaluating agricultural efficiency at a regional or national level since scientific research addressing the efficiency evaluation of European agricultural sector is lacking.

After many applications aiming to support the best management practices at a micro-level, since 2010 scientific interest has begun to rise in relation to the comparison of different agricultural policy visions among countries and their results in terms of efficiency (Table 1). In particular, Hoang and Rao (2010) adopted for the first time a country-based analysis to evaluate the sustainability efficiency of the agriculture sector of 29 OECD countries. In 2011 Moreira and Gomes analyzed, globally, the 40 countries with the largest value added by agricultural sector in 2005, by using output-oriented DEA efficiency measures with variable returns to scale assumption. Their analysis has highlighted that