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Productivity of wastewater treatment plants in the Valencia Region of Spain☆

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ABSTRACT

This study analyses the evolution of productivity over the 2008–2012 period for a homogenous set of 199 wastewater treatment plants that are located in the Valencia Region of Spain and utilize the same treatment technology, using the smoothed bootstrap Malmquist productivity index based on Data Envelopment Analysis (DEA). The results reveal a negative trend in productivity that is mainly the result of resource management rather than an inappropriate level of innovation or use of new technologies. In addition, the effect of exogenous factors on productivity is analysed using the Kruskal-Wallis (KW) test, finding that productivity levels were affected by the quality of the influent water and the size of the plants, but not by the other factors considered.

1. Introduction

The capacity of water bodies to process the ever-increasing pollutant charges from expanding urban, industrial and agricultural water uses is increasingly limited. The adverse impact of anthropogenic pollution on the environment is also on the rise (Lazarova et al., 2012). This situation is further worsened by the increasingly frequent and lengthy periods of drought attributed to climate change (Eurostat, 2009; Gössling et al., 2012; Hof and Schmitt, 2011). Concerns about water supply and quality as well as the severe conditions of water stress found in many regions of the world are expected to escalate.

In this context wastewater reuse is becoming an effective method of reclaiming a percentage of scarce water sources. Since the early 1980s, the general approach has been to treat the wastewater and then either discharge it into the environment, where it mixes with freshwater flows and is indirectly reused downstream, or to use the resulting effluent for agricultural, urban, or industrial purposes (BIO by Deloitte, 2015; Hernández-Sancho et al., 2011c; Lazarova et al., 2012; WWAP, 2012). Although wastewater treatment does not always involve water reuse, this evolving use is becoming widespread (TYPSA, 2013).

In addition to these considerations, there are a number of other justifications for analysing the performance of wastewater treatment plants (WWTPs). Not only can reuse help address the adequacy and ecological status of water masses, as laid down in article 4 of the Framework Water Directive (European Union, 2000), it also has enormous economic potential. Furthermore, one of the principal benefits of wastewater treatment is that it avoids the costs of redressing pollution and the downstream risk of municipalities, industries, farmers, and the tourism industry using contaminated water (WWAP, 2012). From this perspective, it is clear that environmental improvement is one of the factors that justify the importance of analysing the efficiency and productivity of wastewater treatment plants (WWTPs) (De Jong et al., 2000; Laukkanen and Huhtala, 2008; Van der Veeren and Tol, 2001).

The aim of this paper is to study the productivity of wastewater treatment plants using rigorous methods backed by previously published literature. We analyse the influence of both technological changes and the efficiency of processes itself, in an attempt to explain productivity behaviour in a plant over an extended period. Given the potential economic and environmental impact of reuse, we expect the results to be useful to both public managers and private companies in areas facing severe water shortages.

The structure of this report is as follows. A literature review of

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previous research is carried out in section 2. In section 3, the statistical model is explained and described. In section 4, the data used in the study are presented. The results obtained are further explained and discussed in section 5. The conclusions suggest ideas to improve the productivity of the wastewater treatment plants analysed.

2. Literature review

In this section we review previously published papers that analyse both the efficiency and the productivity of WWTPs in order to identify the statistical variables and methods used. Not only have we centred on papers that analyse the productivity of plants, but also on those that analyse efficiency; since the former is merely an evolution of the latter, the variables used in both types of papers should be taken into account, even if the aim of this study is essentially related to productivity.

Many previously published studies have addressed wastewater treatment from a variety of perspectives. However, studies referring exclusively to wastewater treatment productivity and efficiency are scarce. Upon reviewing all the available literature on the subject, we find that only a few have been published on this subject, in Spain. See, for example, Molinos-Senante et al. (2014a,b,c, 2015, 2016), Lorenzo-Toja et al. (2015), Hernández-Sancho et al. (2011a,b,c), Sala-Garrido et al. (2011, 2012a,b), Hernández-Sancho and Sala-Garrido (2005, 2009). At the international level, mention should also be made of the research carried out by Mahmoudi et al. (2012) in Iran and by De Jong et al. (2000) and Kemp (1998) in Dutch WWTPs.

As regards methods, the articles by Abbott et al. (2012), Abbott and Cohen (2009), Covelli et al. (2010), or Ferro et al. (2011) argue that, given how little is known about the production function in the wastewater sector, the most commonly-used methods are those based on nonparametric frontier estimations. Most of those involved in the treatment field use a Data Envelopment Analysis (DEA) approach, although with variations of the models. For example, Molinos-Senante et al. (2014b) use DEA with non-desirable output, Hernández-Sancho et al. (2011b) and Molinos-Senante et al. (2014c) use a non-radial DEA model, and Sala-Garrido et al. (2012a) use a DEA approach with tolerances. Molinos-Senante et al. (2015, 2016) used the Metafrointier Malmquist productivity index (MMPI) and the Hicks-Moorsteen Productivity Index, respectively. Other studies use the influence of more specific aspects, such as the effect of contextual factors on the calculation of economic-environmental efficiency ratios (Lorenzo-Toja et al., 2015; Molinos-Senante et al., 2014a,b; Fuentes et al., 2015), or seasonal influences (Hernández-Sancho et al., 2011c; Sala-Garrido et al., 2012b).

As we analyse the internal structure of these studies, we see that only the samples used vary significantly. They range from 338 WWTPs in the study by Hernández-Sancho and Sala-Garrido (2005, 2009), to the 45 WWTPs in the study by Sala-Garrido et al. (2012a), depending on homogenous subgroups, using a specific technology or treatment process, or referring to a specific area (most of them in the Valencia Region). With the exception of Hernández-Sancho et al. (2011a) and Molinos-Senante et al. (2016), where a 6-year period is considered, and Molinos-Senante et al. (2015), using a 3-year period, almost all of the studies refer to a specific year. A comparison of the variables used on the papers shows similar conclusions. The inputs used vary in terms of aspects ranging from technical data, such as the water mass treated in cubic metres, to purely economic data measured in euros per year, such as operation and maintenance costs, staffing, chemical reagents, or energy costs. The studies by Hernández-Sancho et al. (2011a,b,c), Hernández-Sancho and Sala-Garrido (2005, 2009), Molinos-Senante et al. (2014a,b,c, 2015, 2016), Sala-Garrido et al. (2011, 2012a,b), Lorenzo-Toja et al. (2015) and Fuentes et al. (2015) include the elimination of contaminants from treated water as output, calculated on the basis of entry and output levels of solids in suspension (SS in mg/l) and on the entry and output levels of organic material expressed as a chemical demand for oxygen (COD, in mg/l) or nitrogen. Some also take into consideration non-desirable outputs such as noise, odour and visual impact levels (Molinos-Senante et al., 2014a,b; Lorenzo-Toja et al., 2015). Some studies (for example, Hernández-Sancho et al., 2011a,b; Sala-Garrido et al., 2011, 2012b; Fuentes et al., 2015) use contextual variables, like the characteristics of the effluent, the age or the size of the plant, or the treatment technology.

Table 1 and Fig. 1 present the literature on WWTP efficiency and productivity. Table 1 summarizes the recent studies and Fig. 1 summarizes the variables and models used in the studies.

3. Method

As seen from the literature review, most previous studies carried have either analysed the efficiency or the productivity of WWTPs using non-parametric models, such as the Data Envelopment Analysis model (DEA) or the Free Disposal Hull (FDH), in one of their various forms.

These models have important advantages over parametric models: there is no need to establish the form of the production function; they allow for analysis processes involving various inputs to generate multiple outputs at the same time; they allow the comparison of the activity of each unit (Decision Making Unit - DMU) with the rest (since it is based on an efficient production frontier that includes DMUs, which show higher levels of efficiency); and it is not necessary to make adjustments in situations where the prices of factors and products are either unknown or difficult to calculate.

Until now, these models have been used to evaluate the efficiency and/or productivity of WWTPs while trying to incorporate advances with which to fine-tune the estimates made in this respect, but there is still room for improvement with regard to possible alternatives. Specifically, as proposed in this paper, it is possible to evaluate the productivity of WWTPs over a period in order to observe how it evolves and obtain results using the bootstrap method. That allows us to validate values found, which in general go beyond merely specific information on the sample used as well as build confidence intervals, which makes it possible to contrast the statistical significance of productivity improvements in WWTPs.

Given these advantages and the fact that the majority of the previous studies used DEA to analyse the evolution of WWTP productivity, we also chose to conduct a productivity analysis of the plants using DEA and calculate the DEA-based Malmquist Productivity Index (Malmquist, 1953). DEA allows the units analysed to be organised hierarchically in terms of efficiency levels, whilst the Malmquist index makes it possible to estimate changes in productivity throughout the entire time period of the sample.

In terms of input-oriented evaluation processes, a decision-making unit (DMU) is considered to be efficient when it uses the minimum input empirically observable for any examined DMU, given its output vector (Charnes et al., 1981). In other words, a DMU is inefficient when it cannot use the minimum input level to obtain the maximum output production (Cooper et al., 2004).

DEA is a non-parametric method, where it is not necessary to impose any functional form on the production function and, since it is not stochastic either, it must not be assumed that the non-