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Alternative approaches to the construction of a composite indicator of agricultural sustainability: An application to irrigated agriculture in the Duero basin in Spain

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ABSTRACT

This paper describes a comparative analysis of alternative methods of constructing composite indicators to measure the sustainability of the agricultural sector. The three methods employed were Principal Component Analysis, the Analytic Hierarchy Process and a Multi-Criteria technique. The comparison focused on the irrigated agriculture of the Duero basin in Spain as a case study, using a dataset of indicators previously calculated for various farm types and policy scenarios. The results enabled us to establish a hierarchy of preferred policy scenarios on the basis of the level of sustainability achieved, and show that the most recent CAP reform is the most sustainable agricultural policy scenario. By analyzing the heterogeneity of different farms types in each scenario, we can also determine the main features of the most sustainable farms in each case. The analysis demonstrates that full-time farmers with small to medium-sized farms and sowing profitable crops are the most sustainable farm types in all the policy scenarios. All of this information is useful for the support of agricultural policy design and its implementation, as we attempt to improve the sustainability of this sector.

1. Introduction

"Agricultural sustainability" does not have a single meaning. In any case, as explained by Hansen (1996), there is a wide scientific agreement in considering agricultural sustainability as the ability of agricultural systems to satisfy different demands as times change. However, it is worth pointing out that this definition of sustainability has several difficulties that limit its empirical use in the real world. First, we have to deal with the temporal nature of sustainability. Indeed, this meaning of sustainability, which is related to the maintenance of production capacity, has little practical value because of the infeasibility of performing long-term experiments. Second, we have to deal with the difficulty of identifying the demands that must be satisfied by the agricultural sector if it is to be regarded as sustainable. Sustainability can thus be interpreted as a social concept that can be modified in response to the requirements of society. Thus, the sustainability concept must be regarded as being specific to both time and place. Both of these difficulties have limited the usefulness of this concept as a criterion for guiding agricultural development.

In order to avoid the difficulties mentioned above, a broad consensus has emerged, which regards the concept of sustainability as embodying three main dimensions: environmental, economic and social (Yunlong and Smit, 1994).[1] It can thus be assumed that an agricultural system is sustainable when the trade-offs between the objectives considered for public evaluation of its performance; economic objectives, such as income growth or macroeconomic stability, social objectives, such as equity or the cover of basic needs, and ecological objectives, such as ecosystem protection or natural resources regeneration, reach acceptable values for society as a whole (Hediger, 1999; Stoorvogel et al., 2004). This approximation to agricultural sustainability allows it to be used as an operational criterion, by using a set of indicators that covers the three dimensions mentioned above.

However, the quantification of agricultural sustainability through a set of indicators still has certain shortcomings. The main inconvenience comes from the difficulty of interpreting the complete set of indicators. In order to avoid this problem, it has

[1] As a reviewer points out, this multidimensional feature of sustainability requires multidisciplinary approaches to achieve overall sustainability assessment, taking into account the fields of knowledge of Environmental Sciences, Economics and Sociology.

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been suggested that the analysis of agricultural sustainability could be tackled by aggregating this multidimensional set of indicators into a single index or composite indicator. This approach has been used, for example, by Stockle et al. (1994), Andreoli and Tellarini (2000), Pirazzoli and Castellini (2000), Sands and Podmore (2000), Rigby et al. (2001), van Calker et al. (2006) and Qiu et al. (2007). Nevertheless, the aggregation of indicators for the assessment of agricultural sustainability as done previously has been frequently criticized for a) the subjectivity of the methods employed (the choices of an unique functional form for aggregation and just one weighting technique to establish the relative importance of individual indicators, both of which lack the necessary theoretical background), and b) the commensurability usually regarded as aggregating the individual dimensions or attributes of sustainability (additive aggregation approaches have normally been taken), in spite of their theoretical incommensurability.[2] Both types of problems suggest that the construction of composite indicators for the assessment of agricultural sustainability is still at an early stage, and further developments are in fact needed. This paper tries to partially bridge this gap of knowledge by comparing alternative approaches to calculating a composite indicator in an empirical setting. This comparison could be useful as a way of confirming that the shortcomings pointed out above can be solved by implementing new techniques to build composite indicators or by using jointly different approaches already developed.

Within this general framework, this paper has a double objective. First, from a theoretical perspective, we analyse the pros and cons of alternative methods of building composite indicators of agricultural sustainability (CIAS). This is done empirically by implementing these methods in a real-world case study. Specifically, we apply these methods to quantify the sustainability of irrigated agriculture in the Duero River basin in Spain, using an existing dataset of indicators (Riesgo and Gómez-Limón, 2005, 2006) that covers the three dimensions of sustainability mentioned above. This set of indicators has been calculated for different farm types and future policy scenarios. This feature of the data has enabled us to consider a second objective: to analyse the real possibilities of using the concept of sustainability as a tool to guide the public management of agriculture. The quantitative approach based on the calculation of CIAS is thus used: a) to determine a ranking of policy scenarios on the basis of their sustainability and, b) to identify the most sustainable farm types in each scenario. These results can be useful for public decision-making, from both strategic (encouraging policy actions to promote the most sustainable policy scenarios) and tactical (designing higher levels of support for the most sustainable farms) points of view.

The paper is organized as follows. Section 2 presents the materials, with a brief description of the dataset of indicators utilised for this research (22 farm types $\times$ 12 sustainability indicators $\times$ 6 policy scenarios), which has been obtained from a previous work. Section 3 is devoted to an explanation of the three methods used to calculate the CIAS: Principal Components Analysis (PCA), Analytical Hierarchy Process (AHP) and a Multi-Criteria technique (MCDM) based on the augmented Tchebycheff distance function. Section 4 presents the results obtained, and aims to determine which policy scenarios would lead to more sustainable farming on the 2020 horizon and which are the most sustainable farm types in each of those scenarios. Finally, Section 5 contains a discussion of the results and the conclusions drawn (Fig. 1).

[2] For further details see Hansen (1996), Bockstaller et al. (1997), Morse et al. (2001), Diaz-Balteiro and Romero (2004), Ebert and Welsch (2004), Munda (2005) and Böhringer and Jochem (2007).

Figure 1 is a flow chart that summarizes the individual phases of the study.

2. Materials

2.1. Case study: irrigated agriculture in the Duero basin

The practical application of sustainability needs, first, to determine the geographical scopes of the analysis (Lowrance et al., 1986). In this paper, the empirical analysis focuses on current irrigated agriculture as practised in the Duero basin. This particular agricultural system covers some 563,105 hectares, most of which are devoted to cereals (maize, barley and wheat) and other annual crops (sugar-beet, sunflower and alfalfa). This is thus a typical continental agricultural system, characterized by extensive farming with low-value-added, low-labour-intensive crops and highly dependent on Common Agricultural Policy (CAP) subsidies.

Irrigation in the Duero basin is divided into irrigated areas, known as "Comunidades de Regantes" (CRs). For this study, given the practical impossibility of considering all of them, we selected seven representative CRs at basin level, covering 51,343 irrigated hectares (9.2% of the total irrigated area in the Duero).[3] Fig. 2 shows the location of the Duero basin in Spain, as well as the location of the CRs studied.

All these CRs share the same continental climate, characterized by long cold winters followed by short, hot, dry summers. This is the most productive season, which allows a wide range of crops to be grown. This coincidence of higher temperatures and dry season requires irrigation to allow crops to complete their growing cycle. However, the CRs considered display different characteristics regarding irrigated surface, soil quality, crops grown, number of landowners, etc. Table 1 shows the general features of each CR.

The interest of this case study is due to the recent changes in the policy framework faced by irrigated agriculture. First, the recent CAP reform, approved in June 2003 in Luxembourg that was implemented in Spain in 2006 is worth noting. Of the novelties introduced by this reform, the most important is the partial decoupling of public subsidies received by producers. Furthermore, it is worth pointing out the important implications of the approval of the Water Framework Directive (WFD), which requires the implementation of a new water-pricing policy before 2010, in order to provide adequate incentives to promote the sustainable use of water resources. Both normative novelties make the future of European irrigated agriculture uncertain. This especially concerns the irrigated sector in the Duero basin, due to the predominance of extensive crops with low profitability and heavy dependence on CAP subsidies (winter cereals, maize, sunflowers and sugar-beet, as seen in Table 1).[4] These arguments justify the interest in this analysis of the future sustainability of this case study.

[3] The irrigated areas (CRs) to be analysed were selected through a process of quota sampling, considering size of irrigated areas and location as variables to classify the whole population of CRs in the Duero basin. Once quotas had been calculated for each category, the samples were selected, taking into account the feasibility of data gathering (time and money requirements). Given that this is a non-probabilistic sampling method, it is not possible to guarantee the representativeness of the sample or to calculate a sampling error (Barnett, 1991). In any case, as Brown (1994) pointed out, when the variables used for the classification are adequate, quota sampling shows sufficiently good results. This fact, and the relatively large percentage of irrigated area finally considered (9.2%), can justify the representativeness of the chosen CRs.

[4] As can be seen in the comparative analysis performed by Berbel and Gutiérrez (2004), irrigated agriculture in the Duero basin is the least profitable case study considered in the WADI research project (an average of 701 €/ha of gross margin *versus* more than 2000 €/ha in the cases of Southern Spain, Greece or Italy). This work also shows how farmers practising irrigated agriculture in the Duero basin derived the highest percentage of their income from CAP subsidies (around 35%).