Land Use Policy 75 (2018) 314–326

Contents lists available at ScienceDirect

Land Use Policy

journal homepage: www.elsevier.com/locate/landusepol

Measuring sustainable intensification: Combining composite indicators and efficiency analysis to account for positive externalities in cereal production

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ARTICLE INFO

Keywords:
Sustainable intensification
Composite indicator
Efficiency analysis
Environmental goods
Positive externalities
Distribution-based analysis

ABSTRACT

We combine the use of a stochastic frontier analysis framework and composite indicators for farm provision of environmental goods to obtain a farm level composite indicator reflecting sustainable intensification. The novel sustainable intensification composite indicator that is developed accounts for multidimensional market and non-market outputs, namely the economic performance of cereal farms (i.e. market production value) and the associated positive environmental impacts of production (e.g. positive environmental externalities). The composite indicator integrates three different indicators for the provision of environmental goods into a stochastic frontier analysis: a) agri-environmental payments; b) the ratio of rough grassland and permanent pasture area to total utilised agricultural area; and c) land use diversity, as measured by the Shannon Index. We apply this approach to a panel of data for 106 cereal farms in England and Wales during the period 2010–2012. Results indicate that farm rankings on the indicator vary substantially depending on the weight given to the different environmental aspects/indicators, suggesting that single indicators of the provision of environmental goods may not provide a true reflection of the environmental performance of farms. We illustrate a simple approach that captures the aspects of sustainable intensification of farms in a much more holistic way, i.e. by producing a distribution of sustainable intensification scores for each farm reflecting different weightings of evaluation criteria. To reduce the dimensionality of this distribution farms are classified into four distinct groups according to the shape of this distribution, with some farms found to perform well under all combinations of weights for evaluation criteria, while others always perform poorly. This distribution-based analysis provides a greater depth of information than traditional approaches based on the generation of a single sustainable intensification score.

1. Introduction

A growing awareness of the externalities associated with agricultural production has been a key driver of the development of agricultural policies in the EU for more than 30 years (Potter and Goodwin, 1998). Following decades of policies oriented towards increased productivity in the decades after 1945 (Stoate et al., 2001), without much consideration for the environmental consequences of such an approach, the focus of EU agricultural policy changed from the mid-1980s towards the promotion of a more sustainable agriculture, through provision of incentives to farmers "to work in a sustainable and friendly manner", providing a "better balance between food production and the environment" (European Commission, 2014; Buckwell et al., 2014). Initially, such policies focussed on protection of natural resources, biodiversity and cultural landscapes. In the last 10 years, since the volatility in commodity prices of 2007/8 and growing concerns about food security, attention has moved towards measures aimed at promoting ecosystem services beneficial to production (Plieninger et al., 2012; Tittonell, 2014) and their role in contributing to 'sustainable intensification' (Tilman et al., 2011).

A narrow definition of' sustainable intensification' (SI) is simply improved resource use efficiency, i.e. 'producing more with less'. However, a more complete understanding has to encompass the positive and negative externalities of agriculture, i.e. the supply of ecosystem services beyond provisioning. However, the interlinkages between agricultural production and these environmental outputs, and the trade-offs between them, are complex, making it extremely difficult to envision what sustainable agriculture (or for this matter sustainable intensification) actually comprises (Pretty, 1997). The difficulty in generating models of sustainable intensification in agriculture is compounded by two factors. First, the spatial heterogeneity of both the environments in which agriculture operates and the production systems employed. Second, sustainable intensification in agriculture is an anthropogenic concept that is also subject to heterogeneity, as individuals

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https://doi.org/10.1016/j.landusepol.2018.04.001
Received 14 February 2017; Received in revised form 26 February 2018; Accepted 1 April 2018
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and societies value the ecosystem services provided by agriculture differently and have different levels of awareness and understandings of the interlinkages and trade-offs between these ecosystem services. These differences mean that the definition of sustainable intensification in agriculture, as a concept, varies, even amongst international organisations, although some overlap exists. Thus, for example, the Montpellier Panel and Save and Grow report (FAO, 2011) define sustainable intensification as: "producing more outputs with more efficient use of all inputs - on a durable basis - while reducing environmental damage and building resilience, natural capital and the flow of environmental services"; The Royal Society (2009) defines sustainable intensification as "… yields are increased without adverse environmental impact and without the cultivation of more land"; and the UK Foresight Report (Foresight Report, 2011) states, when referring to sustainable intensification, "simultaneously raising yields, increasing the efficiency with which inputs are used and reducing the negative environmental effects of production". While the first and third definitions are similar, the second definition highlights a slight but important difference, i.e. that SI is considered to be achieved by increasing provisioning services while simultaneously not increasing negative environmental externalities. Taking all these definitions into account, and for the purposes of this study, sustainable intensification can be understood as increasing the market-based dimension of sustainability (i.e. agricultural yield) without decreasing the capacity to provide (largely) non-market dimensions, i.e. environmental services. This understanding of SI evokes the more generalised definition offered by Jules Pretty (Pretty, 1997) that SI represents: "increasing food production from existing farmland while minimising pressure on the environment". These different interpretations of SI have generated a debate about the pathways to achieving SI, with various models being put forward, including land sparing, land sharing, and competitive advantage (Franks, 2014).

While there are different interpretations of what constitutes SI, and consequently different proposed pathways to achieving it, all these approaches face the common problem of how to measure success. The questions arising from this are: (a) what dimensions of SI need to be measured; (b) what metrics are appropriate to capture these dimensions; and (c) how can these metrics be combined into a composite measure of SI that truly reflects the relative importance of each dimension, i.e. under what weighting system?

It seems clear from the definitions above that any meaningful SI measure/metric needs to take into account both provisioning outputs and the environmental impacts of land management, i.e. the inclusion of environmental externalities into technical efficiency analysis. Traditionally, metrics of the environmental dimension have focussed solely on the negative externalities associated with agricultural production. However, there can also be 'positive' environmental outputs associated with productive land management, for example the provision, or improvement, of semi-natural habitats and the positive effects on wildlife and biodiversity that result (Mattison and Norris, 2005; OECD, 1999). Therefore, measuring SI is not the same as measuring sustainability, as the SI measure excludes some key dimensions of sustainability, such as social impacts. In part, this results from limitations on the information available to produce SI, such as, for example, the Defra Farm Business Survey (FBS) data, as used in this study.

Approaches to incorporating environmental externalities into technical efficiency analysis began with Färe et al. (1989). While the focus of this early work was solely directed towards the negative externalities associated with agricultural production (Färe et al., 1989, 1996, 2001; Lansink and Reinhard, 2004; Murty et al., 2006; Reinhard and Thijssen, 2000; Reinhard et al., 1999, 2002) more recent technical efficiency analysis has also incorporated the provision of positive externalities (Omer et al., 2007; Areal et al., 2012; Sipiläinen and Huhtala, 2013; van Rensburg and Mulugeta, 2016). More recently, work by Ang et al. (2015) analysed the impact of dynamic profit maximisation on biodiversity, for a sample of UK cereal farms, using a DEA approach.

The limitation of some of the approaches adopted to date, i.e. that use composite indicators to account for different dimensions of SI, is that these composite indicators can only reflect fixed and usually predetermined relative weightings of these dimensions. Some other approaches to developing composite indicators of SI have not relied on pre-determined weights, but have used statistical procedures such as DEA and factor analysis to determine them. For instance, Barnes and Thomson (2014) used a form of factor analysis to provide weights to individual indicators to form composite indicators of SI. However, the weights for SI indicators obtained in all these previous studies are presented as a single set of numbers, based on the averages of the weight distribution, while variation of these weights is not explored. This may give these composite indicators a form of starting point bias and makes them of limited value to policy makers, who would view the choice of weights for these dimensions as a fully anthropogenic decision. This paper explores the potential for the use in composite SI indicators of a number of different indicators of environmental outputs under multiple weightings, on the basis that all of these alternatives capture some valid aspect of environmental goods at the farm level. To explore the feasibility of constructing such an indicator this study uses a stochastic frontier framework to undertake technical efficiency analysis at the farm level to test a mechanism to create a composite indicator of sustainable intensification combining provisioning outputs with indicators representing multiple dimensions of environmental goods provision.

Since we face farms with multiple outputs (e.g. market and non-market/environmental outputs) we estimate farm level efficiency through the use of an output distance function (Coelli et al., 2005), where the farm production frontier directly accounts for both market and non-market goods.

To overcome the problem of there being no single correct weighting of the relative importance of the different dimensions of environmental output, we explore a method to capture all potential integer weighting combinations within and between the multiple SI indicator. We therefore estimate 66 efficiency stochastic frontier models that account for different combinations of weights for the dimensions of environmental goods provision, to create a single composite indicator for SI. This approach provides a much more nuanced picture (i.e. a probability distribution) of SI at the farm level, than would relying on the use of a single snap-shot, based on a single set of weights.

2. Methods

2.1. Data

The analysis reported here uses data in the form of a balanced panel of 106 specialist cereals farms drawn from the annual Defra Farm Business Survey (FBS) for England and Wales, between 2010 and 2012.[1] Data were drawn solely for the 'specialist cereals' farm type, to minimize the level of heterogeneity due to differences in farming system. While the FBS provides financial data on each farm business, alongside crop, livestock and land use data, it has been historically more limited with respect to environmental metrics (e.g. metres of hedges or pond areas) and physical measures of inputs (e.g. kilograms of nitrogen fertiliser). This has led to the analysis herein drawing on a more limited range of data, and using environmental payments as a composite metric for some environmental outputs, i.e. where these payments can reasonably be assumed to capture public benefit from environmental activities. While drawing on such proxy metrics limits, in part, the results generated, these data are sufficient to demonstrate an approach for quantifying SI that can be further refined in the future through the use of better data. To illustrate, the most recent FBS year (2016/17)

[1] We selected all Specialist Cereals farms that were in the FBS within the period of the study that had all information required for the model (i.e. 106 farms).

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