Computers and Electronics in Agriculture 96 (2013) 209–216

Contents lists available at SciVerse ScienceDirect

Computers and Electronics in Agriculture

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

Development of a proxy for technical efficiency for specialised grain farmers

O. Marinoni *

CSIRO Ecosystem Sciences, Sustainable Agriculture Flagship (SAF), 41 Boggo Road, Dutton Park, Qld 4102, Australia

ARTICLE INFO

Article history:
Received 17 December 2012
Received in revised form 25 May 2013
Accepted 2 June 2013

Keywords:
Remote sensing
Crop simulation
Econometrics
Production efficiency

ABSTRACT

Technical efficiency is the effectiveness with which a given set of inputs is used to produce one or more outputs. As such it is an important indicator that helps to differentiate between production entities that represent current best practice (or operate close to it) from those that do not. State of the art methods to estimate technical efficiency of a production entity are econometric frontier techniques such as data envelopment analysis (DEA) or stochastic frontier analysis (SFA) where observational data on inputs and outputs are analysed. While efficiency scores are then known for the observational units, efficiency scores cannot simply be interpolated to estimate efficiency scores for production units that have not been part of a survey. This paper focuses the development of a proxy measure of technical efficiency for specialised grain farms where no observational data are available for. The proxy measure is based upon crop simulation results and technical efficiencies that are estimated from available survey data. A moderate to strong correlation (0.5–0.7) is found between metrics inferred from crop simulation and technical efficiency scores. Fitted linear models with technical efficiency as the predictor variable returned an R^2 lower equal to 0.42 (linear models have zero intercept). To apply the linear model beyond observed locations, the integration of a remote sensing component is discussed and put into a conceptual framework. The suggested method would be suitable to be applied on a regional level and will help improving the regionalisation of technical efficiency. The findings are based on the analysis of a 4 year plot level survey dataset from Australian grain specialists. Findings are to be considered preliminary at this stage and more research that involves a remote sensing component is needed to confirm the applicability of the suggested framework.

1. Introduction

The technical efficiency of a set of production entities is an important indicator that captures the effectiveness with which outputs are produced. Estimates of technical efficiencies are obtained by analysing observed (surveyed) data on inputs that were needed to produce one or more outputs. Analyses techniques to provide these estimates include data envelopment analysis (DEA) or stochastic frontier analysis (SFA) (Battese, 1992; Coelli et al., 2005). The knowledge of a set of technical efficiencies of production entities within a region and a subsequent regionalisation is important for two reasons: (1) it provides a good understanding of the efficiency within a region and helps identifying top- but also underperformers and (2) if policies and investments are targeted at increasing efficiency and productivity within a region, the spatial knowledge of technical efficiency helps to better target potential investments. Effectively targeted investments in agriculture are important to sustain a certain economic profile within a region but, on a larger scale, are also critical to long term food security. On a global scale, the order of magnitude estimates of the annual investment that is needed to support the expansion of agricultural output is in the range of about US$83b (FAO, 2009).

While efficiency scores are known for the observational units it cannot be assumed that efficiency is, unlike many biophysical parameters, spatially correlated. Thus efficiency scores should not be regionalised by simply interpolating between known observations. In this paper a method is suggested to infer a proxy for technical efficiency for production entities that have not been surveyed, hence where no direct observations for inputs and outputs are available. To do this an approach is put forth which analyses the functional relationship between econometric efficiency scores estimated from available observations and crop simulation model results. To explore possibilities which allow for a regionalisation of technical efficiencies beyond observed locations, it is explored how far remote sensing techniques can be used. Based on the findings of a pilot study a framework is established which uses surveyed data collected at distinct locations, crop simulation and satellite image based remote sensing to provide a regional assessment of technical efficiencies.

* Tel.: +61 738335713.
E-mail address: oswald.marinoni@csiro.au

0168-1699/$ - see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.compag.2013.06.001

In the subsequent sections, the basic principles of productivity and efficiency analysis are provided and a brief review on crop simulation is presented. Combining efficiency analysis, crop simulation and remote sensing captures the farm production perspective, the biophysical and plant physiological perspective, as well as a method that is well suited to monitor crop growth across whole landscapes. Integration of these methods is discussed for specialised grain farming systems only. There are a variety of reasons for this. Grains are amongst the most important agricultural commodities and are grown over vast areas which make them especially suitable for large scale monitoring techniques such as satellite based remote sensing. Another reason to focus on specialised grain farming systems is that these systems produce one major output. This is important as it is investigated whether production efficiency inferred from a sub enterprise entity (plot scale) can be used as a proxy for farm level efficiency. The main objective of the presented approach however is the provision of a way to improve the regionalisation of technical efficiency contributing to a better understanding of its spatial variability within a given region. It is not attempted here to find an alternative measure for a farm level econometric analysis.

2. Methods used

2.1. Productivity analysis

A precise spatial understanding of both agricultural productivity and efficiency is useful knowledge to inform investment decisions that aim at increasing productivity within a region. To capture the efficiency of a production system econometric efficiency analyses methods that use frontier techniques such as DEA or SFA can be used. These techniques analyse reported production data on inputs (e.g. amount of fertiliser or seed used, labour, etc.) and outputs (e.g. yield achieved) across a number of production entities (decision making units) to infer an efficiency frontier and provide efficiency score estimates for each observational unit.

The term DEA was first used by Charnes et al. (1978) but alternative approaches based upon different assumptions for example by Banker et al. (1984) exist as well. DEA is a non-stochastic approach that uses linear programming to construct a non-parametric frontier (hull) over the data. Unlike DEA, SFA represents a parametric approach. It requires the specification of a production function model (e.g. a Cobb–Douglas function, translog) but also integrates a stochastic error component and thus accounts for statistical noise in the data. SFA has independently been proposed by Aigner et al. (1977) and Meeusen and Vandenbroeck (1977). The data used in this study where analysed using both techniques, DEA and SFA.

In DEA, the efficiency of a production entity (or farm) p is obtained by solving the linear program

$$\begin{aligned} \text{max.} \quad & \sum_{k=1}^{n} v_k q_{kp} \\ \text{s.t.} \quad & \sum_{j=1}^{m} u_j x_{jp} = 1 \\ & \sum_{k=1}^{n} v_k q_{ki} - \sum_{j=1}^{m} u_j x_{ji} \leqslant 0 \ \forall i \\ & v_k, u_j \geqslant 0 \ \forall k, j \end{aligned} \tag{1}$$

where q_{ki} is the amount of output k produced by farm i, x_{ji} the amount of input j used by farm i, v_k the weight given to output k, u_j the weight given to input j, n the number of outputs, and m is the number of inputs.

DEA provides an efficiency rating between zero and one. The most efficient production units have a technical efficiency of 1; scores lower than 1 imply inefficiency.

In contrast to DEA, SFA requires the specification of a production function. The production function used in this study was a Cobb–Douglas function (Eq. (2)) which is frequently used in agricultural production studies (Battese, 1992; Bravo-Ureta and Pinheiro, 1993; Moreira et al., 2006; Neumann et al., 2010; Thiam et al., 2001). The function is specified as follows:

$$\ln q_i = \beta_0 + \sum_{k=1}^{k} \beta_k \ln x_{ki} + v_i - u_i \tag{2}$$

where i is the index for a farm i, v_i is a symmetric random error term representing approximation errors and other sources of statistical noise and u_i is a non-negative random variable representing technical inefficiency, β is a vector of coefficients of the production function which need to be estimated, q_i is the output of farm i and x_{ki} the kth input of farm i. The technical efficiency of a farm is then the ratio of observed output to the corresponding stochastic frontier output (Coelli et al., 2005). Other production functions can potentially be used as well (e.g. a translog function). As to the choice of the functional form a variety of studies concluded that different model choices lead to consistent results and the impact of the choice of the model on estimates of efficiency is rather small (Ahmad and BravoUreta, 1996; Koop and Smith, 1980; Thiam et al., 2001).

2.1.1. Schematic interpretation of technical efficiency

Fig. 1 shows a generic example of an efficiency frontier which is inferred by analysing the aggregated inputs (e.g. seed, labour, etc.) farms have used to produce a certain output, e.g. tons of yield. Each point in Fig. 1 represents a farm in the input–output space for a given period T_t. The efficiency (or "best practise") frontier is defined by the "top performers"; points on the efficiency frontier are "technically efficient" (Vercellis, 2009); they have a technical efficiency score TE of 1. If a more efficient technology has been implemented at time T_{t+t1} and an analysis is repeated then top performing farms might be moving beyond the frontier that existed at T_t thus defining a new efficiency frontier. Shifts of the efficiency frontier therefore represent a technical change TC which can be caused for example by an introduction of new crop varieties. Many other points below the original frontier might move upward as well thus representing the tendency of farms to move closer to "catch" the frontier. Thus technical efficiency scores are not a constant associated to a production entity but change in time as well (=technical efficiency change TEC). These changes can be related to technical equipment used, management quality, education or simply be a result of financial resources available to farmers (Squires and Tabor, 1991). There is a variety of efficiency measures which can potentially be explored (e.g. scale efficiency, efficiency of the mix of inputs used, etc.) and technical efficiency is just one of them. To understand which production units are inefficient and how to improve them, all the types of efficiency (or inefficiency respectively) present need to be separately measured (Sherman and Zhu, 2006). This paper focuses the technical efficiency component only as it is assumed that a plausible link to results of crop simulation and remote sensing techniques can be established (see discussion in following sections). In regards to a more fundamental discussion of efficiency analysis, the reader is referred to (Coelli et al., 2005; Hughes et al., 2011; Mullen and Crean, 2007) and the references provided therein.

2.2. Crop growth models

Crop growth models provide the methodological toolkit to model the growth of a crop at a point scale and account for