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Analysis

The value of environment across efficiency quantiles: A conditional regression quantiles analysis of rangelands beef production in north Eastern Australia

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ABSTRACT

In agricultural systems the value of environmental inputs can be measured using the production function approach whereby the marginal contributions of factors are associated with a shadow value under perfect competition and rationality assumptions. However, empirical studies show that inefficiency in production is common indicating that the rationality assumption is not met. Furthermore, substantial evidence exists to suggest that the contributions of environmental inputs in particular may be differentiated across the efficiency distribution. This means that the frontier technology may not be an appropriate reflection of the technology in use by inefficient enterprises. This article presents the use of conditional regression quantiles to consider how the value of environmental inputs, measured by their contributions to production, vary across efficiency quantiles. We employed a case study of rangelands beef production in Australia to consider how environmental health differentially contributes to production values across efficiency quantiles. Our approach generates detailed insights into the nature of environmentally-sourced technical inefficiency and suggests that conditional quantile regression approaches are ideal for consideration of issues wherein substantial heterogeneity exists limiting the information content of conditional mean based analyses.

1. Introduction

A key question for parties interested in procuring environmental improvements in agricultural areas is whether improvements in environmental outcomes involve positive opportunity costs. Under assumptions of perfect information and rationality of enterprise managers differences in the use of environmental factors, or level of environmental pollution, boil down to differences in production technologies and relative prices. In this 'rational', world improvements in environmental outcomes involve movements away from an optimal mix of inputs to an a priori sub-optimal mix and thus involve an explicit opportunity cost (Altman, 2001). Evidence for the presence of inefficiency in production is, however, widespread. The marginal contributions of human inputs to production have generally been widely studied and are well-known yet inefficiency rather than efficiency is still found to be the norm even when controlling for different technologies (e.g., Battese et al., 2004; Villano et al., 2010) and state dependence in production technologies (e.g. O'Donnell et al., 2010). Where producers are not at optimum levels of efficiency it is possible that Pareto improvements may be achieved without reversion to compensatory methods because increases in efficiency, and thus profitability, may be associated with improvements in environmental factors (Altman, 2001; Pannell, 2008). Current approaches to the assessment of technical efficiency are, however, limited in that they typically only consider homogenous changes in technologies: i.e. they cannot consider how the use of environmental inputs, and their contributions or coincidence with output, varies with the efficiency level of the enterprise.

In this study we consider the contributions of environmental factors to enterprise efficiency in the context of environmental health and livestock enterprises operating in the north eastern Australian rangelands. The approach we take is novel in that production functions for each percentile across the majority of the efficiency distribution are estimated allowing consideration of how the production technology, incorporating environmental inputs, changes across efficiency quantiles. The value of environmental factors is then considered across efficiency quantiles using the production function approach to environmental valuation (Barbier, 2000; Freeman, 1993) allowing description of the contributions of environmental inputs to enterprise inefficiency. Using this approach, we are able to consider whether the opportunity costs of improving supply of environmental benefits differs across efficiency quantiles. The approach is unique in that it purposely exploits the semi-parametric nature of conditional regression quantiles to generate estimates of intercept and slope parameters for a production function at different locations in efficiency space – an approach that is novel in the environmental valuation space. Changes in the slope parameters

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are analysed in terms of changes in production structures related to use of environmental inputs across these efficiency quantiles and hence the value of environmental inputs across efficiency quantiles.

In the following we present a brief background to the measurement of environmental value and the contributions of environmental inputs to enterprise efficiency (Section 2). Section 3 provides an overview of the conditional regression quantiles methodology and linkages to enterprise efficiency measurement. An overview of our data and case study is provided in Section 4. The econometric methods utilised, including Ordinary Least Squares (OLS) and Stochastic Frontier Analysis (SFA) methods, are outlined in Section 5. Results are presented in Section 6 separately considering comparisons between quantile regression, OLS and SFA methods (Section 6.1) and inference on the results of the quantile regression approach (Section 6.2). Conclusions provide further interpretation of our results and the potential for quantile regression methods to improve information on consideration of environmental contributions to economic activity in the future.

2. Environmental Inputs and Enterprise Inefficiency

Evidence for the contributions of environmental factors to inefficiency is becoming more prevalent with recent research showing how efficiency is related to environmental factors as an externality. For example, Asche et al. (2009) show that cost efficiency in an aquaculture industry is directly related to environmental pollution via over-feeding of fish stock. Reinhard et al. (2002) consider environmental efficiency directly via a two-stage stochastic frontier model approach. Løvold Rødseth (2013) and Hoang and Nguyen (2013) present analyses of environmental efficiency from the perspective of the materials balance condition. Altman (2001) links environmental efficiency to social values for improvement by showing that, in the presence of inefficiency, environmental improvements can be achieved without cost-of-production increases.

In many cases however environmental factors play a direct role as inputs in the production function (Freeman, 1993; Considine and Larson, 2006) rather than being related to production as an externality. In these cases interest centres on the direct contributions environmental factors have on production for efficient enterprises. Under the presence of inefficiency associated with sub-optimal management of environmental assets it is possible that provision of incentives for environmental improvements in these cases may entail some crowding out of efficient environmental provision in a similar form to the outcomes presented by Kits et al. (2014) on motivational crowding out. Furthermore, the case of non-neutrality in the effects of environmental usage on enterprise efficiency suggests that generally enterprises will have different opportunity costs for environmental improvements across the distribution of inefficiency.

Models of the average or most efficient value of environmental inputs to producers rely heavily on the assumption that enterprise or environmental inefficiency affects the production technology in a homogenous way: i.e. optimisation failures simply scale the frontier technology to less efficient locations. However there is substantial empirical evidence that the homogeneity constraint for efficiency measurement is implausible. For example, Greene (1993) comments that the slope parameters of the frontier model can be consistently estimated by OLS in the same volume as Lovell (1993) suggests that a central tenet of some early efficiency studies was the exploration of scale and substitution possibilities differences between relatively efficient and relatively inefficient enterprises. The former claim suggests that efficiency effects are homogenous whilst the latter suggests they are not. Coelli et al. (2005) also suggest the unbiased nature of OLS approaches stating that 'we can obtain consistent estimators of the *slope* coefficients using Ordinary Least Squares' (page 245). However differences between OLS and SFA estimated parameters are consistently found (Lovell, 1993) indicating that OLS estimates are not consistent estimators of frontier marginal effects.

Practitioners of frontier analysis methods have recently begun to recognise the limitations of assuming representativeness of a single estimated production frontier by describing the possibility that different technologies may exist in a single industry or region resulting in the presence of non-continuous technology gaps (O'Donnell et al., 2007; Villano et al., 2010). The approach presented in this paper, conditional regression quantiles, allows for exploration of differences in production technologies and associated economic measures of value at frontier and non-frontier locations of the production set. Compared to OLS and SFA approaches this is a potentially a major advance if inefficiency has non-homogenous effects on the production technology. A conditional quantile regression function can, theoretically, be estimated for any percentile of the conditional distribution of output. In Section 3 this relation is shown to be analogous to the estimation of isoquants for different technical efficiency quantiles.

In order to assess the value of environmental inputs across efficiency quantiles the 'production function approach' to environmental valuation (Freeman, 1993; Barbier 2000) was used. This approach involves the attribution of value based on the fact that many environmental inputs contribute to production either in a positive way (e.g. rainfall, soil health) or a negative way (e.g. acid rain). When enterprises operate in competitive input and output markets and enterprises are rational profit maximisers, the marginal product (MP) of an input is proportional to the Marginal Value Product (MVP) which itself is equal to the Marginal Cost (MC) of inputs. This provides a rationale for the valuation of un-priced inputs utilised in productive activities (Freeman, 1993): Under the competitive markets hypothesis, the MP is an indicator of value for non-market inputs such as environmental health in a production function for an agricultural enterprise. Thus, the ability to estimate production technologies for different levels of enterprise efficiency allows direct consideration of how the shadow values for environmental inputs changes as efficiency changes.

Comparisons of input–productivity and value differences across efficiency quantiles were considered using the concepts of output elasticity which measures the percentage change in output for a percentage change in an input, Returns To Scale (RTS) which measures the percentage change in output for a percentage change in all inputs together and the Marginal Product (MP) which measures the change in output for a small change in an input and is an indicator of the implicit price of an input when enterprises are operating in competitive input and output markets. These are represented as:

$$\eta_i = \frac{\mathrm{d}Q}{\mathrm{d}x_i}\frac{\Delta x_i}{\Delta Q} (\text{Output Elasticity for input } i)$$
$$RTS = \sum_{i=1}^{K} \eta_i (RTS \text{ for inputs } k)$$
$$MP = \frac{\mathrm{d}Q}{\mathrm{d}x_i} (\text{Marginal Products for input } i).$$

An enterprise is said to have 'increasing RTS' if the RTS score for all variable inputs is greater than 1, 'constant RTS' if the RTS score for all variable inputs is equal to 1 and 'decreasing RTS' if the RTS score for all variable inputs is less than one. As the RTS score is equal to the sum of output elasticities across variable inputs, if any one input is associated with an output elasticity greater than 1, than the RTS will be increasing (assuming all inputs have a positive MP). The RTS is a measure of scale efficiency in an enterprise (Coelli et al., 2005) and thus has a clear relation to enterprise productivity. We include measures of output elasticity and RTS because they provide an indication of the sources of relative productivity across alternative inputs and provide an indication of whether enterprises using different production technologies are scale efficient.