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Analysis

Incorporating measures of grassland productivity into efficiency estimates for livestock grazing on the Qinghai-Tibetan Plateau in China

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ABSTRACT

Incorporating an ecological variable for the productive capacity of the grassland into the production function is a new step toward conducting technical efficiency analysis for livestock grazing. This variable is generated using remotely sensed net primary productivity (NPP) data and available grassland area, and entitled as grassland total NPP capacity. With the one-step approach of using a multi-output, multi-input stochastic input-oriented distance function based on field survey data combined with NPP data, we estimated the technical efficiency of livestock grazing on the Qinghai-Tibetan Plateau using two measurements related to ecological performance, an environmental performance indicator and environmental efficiency. The average technical efficiency is estimated to be 0.837 when considering grassland total NPP capacity, implying that livestock grazing inputs can be decreased by 16.3% without any reduction in outputs. The average environmental performance indicator is estimated to be 0.013, representing the effects in association with NPP per unit grassland. Environmental efficiency is about 0.123, meaning there might be overuse of grassland total NPP capacity in livestock grazing, in terms of overuse of grassland size or overuse of NPP per unit grassland. Understanding relationship between technical efficiency and ecological performance would be helpful for balancing local economic development and environmental protection.

1. Introduction

Livestock grazing is of importance worldwide economically but also for ecosystem services. Livestock production faces pressure from increasing demand for meat, food safety, and environmentally sound management (McDowell, 2008). Grassland grazing can produce meat with relatively little use of synthetic fertilizers, chemicals or water, but at the same time, overstocking can cause erosion through trampling and treading, as well as through decreased plant cover (Taboada et al., 2011). Although grasslands support livestock grazing and provide ecosystem services, three-quarters of the world's grazing lands have lost more than 25% of their capacity to support animals (White et al., 2000; UNEP, 2005). The Qinghai grassland area is one of the biggest grassland areas in China. Part of the Qinghai-Tibetan Plateau has been heavily affected by inappropriate cultivation and abuse from collection of fuel and medical plants. Livestock grazing, of yaks and Tibetan sheep, is the most widespread land use on the Qinghai-Tibetan Plateau and long-term overgrazing has been argued to be a widespread problem (Zhou et al., 2006; Akiyama and Kawamura, 2007; Zhang, 2008). Overgrazing has been defined by comparing actual and proper livestock carrying capacity on the Qinghai-Tibetan Plateau, and proper carrying capacity, though a controversial concept in itself (Vetter 2005), was notably exceeded from 1988 to 2005 (Fan et al., 2011). Although grazing pressure has been reduced since, overgrazing has been reported in studies as recently as 2010 (Zhang et al., 2014). The potentially strong relationship between total NPP and livestock grazing capacity led to our interest in researching the productivity and technical efficiency of livestock grazing incorporating ecological factors, in particular grassland Net Primary Productivity (NPP) per unit area, as representative of grassland quality. Presumably, grazing regularly exceeds net primary production annually would be another indicator of overgrazing.

Typically land area size is one of the necessary inputs in assessing agricultural crop farming or livestock grazing. There are many research publications that use the size of the land area available to a household as one of the inputs, including for crop farming (Pascual, 2005; Brümmer et al., 2006; Galdeano-Gómez and Céspedes-Lorente, 2008; Chen et al., 2009; Zhang et al., 2011; Asante et al., 2014), livestock grazing, and dairy farming (Morrison Paul et al., 2000; Brümmer et al., 2002; Lansink et al., 2002; Morrison Paul and Nehring, 2005; Otieno et al., 2014; Sauer and Latacz-Lohmann, 2014). However, few papers consider the heterogeneity of land quality as influenced by soil nutrients, soil

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type, or soil conservation (Reinhard et al., 2002; Latruffe et al., 2004; Bozoglu and Ceyhan, 2007; Hoang and Alauddin, 2012; Marchand, 2012; Rao et al., 2012). To the best of our knowledge, even fewer papers focus on the environmental performance of livestock grazing, and take grassland quality into account for grazing on the Qinghai-Tibetan Plateau.

As the characteristic in the grasslands of the Qinghai-Tibetan Plateau, grassland quality is heterogeneous in terms of species diversity, vegetation biomass, soil nutrients and so on (Li et al., 2013). Unlike dairy farming, where capital and human management play important roles in production potential, livestock grazing relies heavily on the grassland itself, especially in the case of extensive livestock grazing on unfertilized native grassland in the Qinghai-Tibetan Plateau. The average pasture area is about 54 ha for each grazing family from our field survey. Therefore, we consider both grassland area and grassland quality in this paper, where the grassland quality is represented by grassland NPP per unit. We refer to this combination as a measure of "grassland total Net Primary Productivity capacity" (TNPP), which is equaled to be grassland NPP per unit multiplying grassland area. Using the ecological variable NPP to be representation of grassland quality, we measure the environmental performance indicator and environmental efficiency of livestock grazing, as a contribution to ecological performance measurement.

Eco-efficiency and environmental efficiency have become heated topics within the field of productivity and efficiency analysis in the economics literature. These terms were developed to express the performance of ecological factors and environmental factors in meeting human demand (OECD, 1998; Huppes and Ishikawa, 2005). The formal definition of eco-efficiency can probably be attributed to the World Business Council for Sustainable Development (WBCSD) in the beginning of the 1990s (WBCSD, 1992). They described eco-efficiency as the ratio of reduced environmental impact to increased value of production. Similarly, eco-efficiency is defined as the ratio between economic value added and environmental pressure exerted (Kuosmanen and Kortelainen, 2005; Beltrán-Esteve et al., 2014). Environmental efficiency is used pervasively regarding to environmental input or environmental output in the production function, for instance, environmental efficiency equals to ratio of minimum input of environmental detriment to observed input (Reinhard et al., 1999, 2002) or environmental efficiency of a firm equals the ratio of minimum nutrients over observed nutrients (Coelli et al., 2007; Hoang and Coelli, 2011; Hoang and Nguyen, 2013; Guesmi and Serra, 2015). We focus on environmental efficiency and environmental performance indicators in this paper.

Empirical approaches for measuring environmental efficiency can be divided into three main groups. First, environmental efficiency is measured by the performance of environmental factors. Many empirical environmental methodologies have been proposed for the measurement of environmental performance of production units (Yaisawarng and Klein, 1994; Färe et al., 1996; Tyteca, 1996; Picazo-Tadeo et al., 2014). Second, environmentally detrimental inputs and pollution may be treated as inputs in the production function (Pittman, 1981; Reinhard et al., 1999, 2000, 2002; Marchand and Guo, 2014). Third, environmentally detrimental effects may be treated as undesirable outputs, or "bad outputs", in the production function (Färe et al., 1986, 1989, 2005; Van Ha et al., 2008; Cuesta et al., 2009; Feng and Serletis, 2014; Picazo-Tadeo et al., 2014). Both nonparametric (e.g. data envelopment analysis, nonparametric hyperbolic distance function) and parametric approaches (e.g. radial distance function, directional distance function) have been used frequently in the measurement of environmental efficiency. In this paper, we contribute to environmental efficiency analysis by incorporating an ecological variable in the production function.

We extend the contribution of Reinhard et al. (1999, 2002) for environmental efficiency by incorporating the total NPP capacity of the available grassland as one of the inputs in the production function, and define the environmental performance indicator[3] by comparing the technical efficiency estimates from a model that includes grassland total NPP capacity with a model that does not incorporate grassland total NPP capacity. The stochastic input-oriented distance function with maximum likelihood estimate (MLE) estimation procedure is developed using household level data for livestock grazing. As there are a growing number of extension and policy programs designed to mitigate the impact of livestock grazing on the environment and social sustainability, the goal is a deeper understanding of the environmental performance of livestock grazing and to support policies that help sustainable development of the regional environment.

In order to provide a more comprehensive picture of the sustainability of the land-use system in the Qinghai-Tibetan Plateau, an ecological economics perspective would be desirable. With our study, we aim to provide one important building block of such a comprehensive picture by combining various strands of thought in economics to develop an empirically tractable assessment of environmental performance. We combine elements from institutional economics, in particular allowing farmers to be technically inefficient and environmental economics, in particular the relevance of environmental indicators for producing marketed outputs, and grassland ecology, in particular the role of grassland quality differences in an environmental efficiency assessment.

The structure of the paper is as follows. Section 2 presents the theoretical framework, methodology and empirical model specifications. Section 3 contains data and statistical descriptions. The empirical model analysis results are presented in Section 4, followed by Section 5 which offers conclusions and discussions.

2. Theoretical Framework and Methodology

In order to estimate the technical efficiency, an environmental performance indicator and the environmental efficiency of livestock grazing, a multi-input multi-output livestock husbandry production function incorporating the ecological variable as one of the inputs are developed. We estimate the stochastic distance function and technical inefficiency model first, derived from which we calculate the environmental performance indicator and environmental efficiency. As livestock grazing on the Qinghai-Tibetan Plateau in our study area still relies on seasonal use of pastures with rotational stocking (Davies and Hatfield, 2007; Harris, 2010), this might be advantageous for the distance function because the distance function does not consider the price of inputs and outputs. Given the properties of the output-oriented (output) distance function and the input-oriented (input) distance function, we use an input-oriented stochastic distance function to address our research questions in this paper, because the extensive livestock husbandry on the Qinghai-Tibetan Plateau heavily relies on grassland area and grass quality and the input-oriented stochastic distance function sheds more light on the inputs of the grassland total NPP capacity. We adopt the stochastic distance function approach instead of a deterministic approach because of the ability to separate random noise from the technical inefficiency term.

2.1. Conceptual Framework

We followed the distance function developed by Shephard (1970), which treats the outputs as given and adjusts the input vectors as long as the input–output vectors are still technologically feasible. Defining herding households using input sets, $L(y)$, which represent the set of all output vector sets $y \in \mathfrak{R}^{M+}$ can be produced by input vectors, $x \in \mathfrak{R}^{K+}$, which can be written with the input possibility set $L(y) = \{x : x \text{ can produce } y\}$. This is assumed to satisfy the set of axioms depicted by Färe et al. (1996). The input distance is then defined as $D_I(x,y) = \sup\{\rho : (y/\rho) \in L(y)\}$, where ρ means distance from the producer point to frontier (Kumbhakar and Lovell, 2000). The translog

[3] Different definition of terminology "Environmental performance indicator" could be referred to Färe et al. (1993, 1996), Tyteca (1997), and Hailu and Veeman (2000).