Agricultural Systems 133 (2015) 73–84

Contents lists available at ScienceDirect

Agricultural Systems

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

Efficient economic and environmental management of pastoral systems: Theory and application

Graeme J. Doole [a,b,*], Ross Kingwell [c]

[a] Centre for Environmental Economics and Policy, School of Agricultural and Resource Economics, University of Western Australia, 35 Stirling Highway, Crawley, WA 6009, Australia
[b] Department of Economics, Waikato Management School, University of Waikato, Private Bag 3105, Hamilton 3240, New Zealand
[c] Department of Agriculture and Food (Western Australia), 3 Baron-Hay Court, South Perth, WA 6151, Australia

ARTICLE INFO

Article history:
Received 18 August 2014
Received in revised form 16 October 2014
Accepted 31 October 2014
Available online 15 November 2014

Keywords:
Efficiency
Trade-off curves
Livestock
Supplement

ABSTRACT

A framework for interpreting profit–environmental trade-offs in pastoral agriculture is introduced, drawing on the concepts of economic and environmental efficiency. The approach provides insights into appropriate policy mechanisms to address the environmental footprint of agricultural production. The framework is applied in the context of nitrogen leaching from pasture-based New Zealand dairy farms. This application identifies that the economic and environmental efficiency of these farms is mainly driven by imported supplement use. Grass-only farming is environmentally-efficient, with greater supplementation generating higher nutrient outflows to waterways. However, profits increase with higher supplementation within a critical range of intensification. Economic efficiency requires low use of supplement to promote herbage utilisation and reduce pasture senescence at low stocking rates, combined with high use of supplement to fill critical feed deficits at high stocking rates. Model output suggests that there exists scope for win/win solutions for private/public agents through improving the conversion of supplement to milk on New Zealand dairy farms. However, the scope to achieve such gains may be restricted in reality, given incentives for intensification, the potential cost of intensive farm planning, and personal barriers to behaviour change.

1. Introduction

Livestock grazing is the most extensive land use worldwide, occurring on around a quarter of the global land area (Asner et al., 2004). It is predicted to play an increasingly important role in food security for a growing population, with livestock production predicted to grow by 80% across 2005–2050 (Alexandratos and Bruinsma, 2012). However, advances in management will have to occur, if environmental resources are not to subsequently degrade (van Vuuren and Chilibroste, 2013). For example, global milk production has expanded to match population growth over the last 50 years, but its impact on atmospheric emissions and nutrient outflows to aquatic ecosystems is of increasing concern (Berre et al., 2014).

Economic analysis can help elucidate how grazing systems can improve their profitability and environmental sustainability. One approach entails using optimisation models to determine the empirical relationship between profit and an individual environmental indicator – usually termed a trade-off curve – for a given farm (Weersink et al., 2002; Zander and Kachele, 1999). This practice exploits the wide use of optimisation models to identify how producers can increase farm income within the constraints posed by available biophysical, managerial, and technical resources (Hazell and Norton, 1986; Kaiser and Messer, 2011). Trade-off curves have now been applied worldwide to conceptualise the relationship between economic and environmental outcomes for agricultural systems (Bobojonov and Hassan, 2014; Meyer-Aurich, 2005; Robertson et al., 2009; Wu et al., 2014).

A more popular methodology involves the estimation of environmental-efficiency frontiers from input and output data collected for individual firms (Oude Lansink and Wall, 2014). These approaches involve the estimation of a frontier upon which firms that produce a given level of output with the least environmental emissions are placed (Oude Lansink and Wall, 2014; Reinhard et al., 2000). During the application of this procedure, an efficiency score is estimated for each individual firm within the sample, which specifies how efficient this firm is relative to those upon the frontier (Coelli et al., 2005; Dyckhoff and Allen, 2001). Consideration of environmental resource use through frontier estimation extends the traditional paradigm employed for efficiency analysis in economics (Fried et al., 2008; Hailu and Veenman, 2001). Given the strong theoretical foundations and broad application of efficiency analysis, these methods have now been widely applied to study

* Corresponding author. Tel.: +64 +7 838-4134; fax: +64 +7 838-4331.
E-mail address: gdoole@waikato.ac.nz (G.J. Doole).

http://dx.doi.org/10.1016/j.agsy.2014.10.011
0308-521X/

environmental efficiency, even in the particular case of livestock systems (Asmild and Hougaard, 2006; Berre et al., 2014; Coelli et al., 2007; Fraser and Cordina, 1999; Ramilan et al., 2011; Reinhard and Thijssen, 2000; Reinhard et al., 2000; Toma et al., 2013).

However, though widely used, the application of frontier methods to the analysis of livestock systems is challenging for several reasons:

1. The incorporation of environmental impacts within frontier analysis is not seamless and typically requires heuristic assumptions. Environmental impacts can be interpreted as a production input (Hailu and Veenman, 2001; Reinhard and Thijssen, 2000), but this can lead to inconsistencies between the use of standard inputs and environmental inputs (Coelli et al., 2007; Fare and Grosskopf, 2003). Environmental impacts can instead be represented as an undesirable output (Berre et al., 2014; Fare et al., 1989), but this does not allow situations where farms can reduce pollution, but also maintain or improve production (Ramilan et al., 2011).
2. Frontier analysis also requires firm data of an appropriate quantity and quality. This is problematic in many practical instances, given the scarcity of data and the sensitivity of results to small perturbations within it (Tyteca, 1996). This is evident in frontier analyses performed for New Zealand (NZ) dairy systems, where data scarcity has motivated the use of national data sets (Jiang, 2011) or those that have been artificially generated (Ramilan et al., 2011). In particular, the quantity and quality of farm data relating to revenue, cost, and profit are generally poor, which has stimulated a focus on physical measures of input and output use in efficiency analysis (Coelli et al., 2005; Tyteca, 1996).
3. Frontier analysis also provides a simplistic characterisation of the production process (Berre et al., 2014), with failure to recognise explicit linkages between different inputs within the biophysical system potentially misguiding any analysis of environmental efficiency.
4. Inherent in frontier estimation is the assumption that inefficient producers can replicate the management of efficient farms. This is problematic, given broad diversity in management skill, biophysical resources, and risk preferences among a population.

Notwithstanding these limitations, efficiency concepts are very pertinent for the study of livestock systems, as society is faced with feeding more people with less environmental degradation. Thus, this study diverges from previous work through integrating important concepts from efficiency analysis with a formalism based on the trade-off curve approach.

The primary objective of this work is to present a conceptual framework for understanding profit and environmental efficiency within livestock systems, as a step towards an improved understanding of these concepts in pastoral agriculture. The conceptual framework is based on the delineation of a trade-off curve, which denotes the maximum profit that a given farming system can earn for a given level of environmental impact. It interprets how a given firm may transition from one management plan to another, within the context of efficiency principles. It is typical for firms to be inefficient in the use of their resources. For example, Jiang (2011) identified that less than 3% of farms in her sample were operating at full efficiency. The framework allows the development of an integrated understanding of what characterises inefficient firms and how they can improve their management, in terms of both profit and environmental efficiency. It represents a valuable alternative to frontier analysis through: (a) its capacity to study a single farming system at a high degree of detail; (b) explicitly consider the complex biophysical processes present in an agricultural system; (c) low reliance on rich regional data sets, especially those including financial records; (d) avoidance of heuristic assumptions regarding how environmental impacts should be defined in a classical frontier formalism; and (e) capacity to represent management improvements that involve lower environmental impacts, but with no concomitant drop in production.

The application of this conceptual framework can be used to develop broad insights into how farming systems within a region or nation need to adapt to improve profit and environmental outcomes. This is evident in the empirical application to be discussed later, where the case study is applied in the context of nitrogen (N) leaching from intensive pasture-based dairy farms in NZ. The NZ dairy industry produces a quarter of this nation's merchandise exports, but is under significant societal pressure to reduce its nutrient outflows to waterways (Monaghan and de Klein, 2014). An explicit focus of this application is the use of expert information to ensure that the alternate farm plans generated in this application are representative of existing farm types in the study region. By assessing the relative efficiency of these systems, from both an economic and environmental perspective, it is possible to highlight how producers can improve private and public outcomes for the assumed set of biophysical resources that define this representative farm unit.

2. Theory

2.1. Framework

This section introduces a framework for understanding economic and environmental efficiency in agricultural systems. It focuses on the relative value of alternative farm plans. Relative value depends on many factors, including diversity in farm profit, financial costs of the transition, impact of variability in the decision-making environment, the risk preferences of the farmer, the ability of the farmer to manage change, and so on (Pannell et al., 2006). Nevertheless, this study compares solutions solely on the basis of farm profit, following the standard use of trade-off curves (e.g. Weersink et al., 2002), importance of profit to firm viability (Mishra and Goodwin, 1997), and importance of profit to the adoption of conservation practices (Pannell et al., 2014).

The standard means to relate outputs of agricultural production, such as milk and N leaching, to input use on farms is through a production function. A production function represents the maximum output attainable for a given level of use of variable and fixed inputs (Fandel, 1991). Primary methods of analysing production functions in economics concern the use of optimisation models of individual farming systems and econometric estimation based on firm-level data (Kingwell, 1996). Econometric methods involve estimation using single equations (Just, 1983), dual systems of output and input demand equations (Heckelei and Wolff, 2003), and frontier methods (Coelli et al., 2005). While both optimisation and econometric approaches share a similar grounding in the microeconomic theory of the firm, their structure and specification are highly disparate (Heckelei and Wolff, 2003). This investigation focuses solely on the use of an optimisation model (Section 3), to provide a rich description of the key biophysical processes present and avoid limitations associated with data quantity and quality (Just, 1983). Econometric methods impose minimal structure on biophysical processes, potentially misguiding any analysis of how inputs and outputs are related in agricultural systems. This helps to justify the use of an optimisation model to study production response in this context.

Figure 1 presents the basis for the conceptual framework, within the context of the case study. A concave trade-off curve is presented, depicting the relationship between N leaching[1] on the

[1] This is understood to be the proportion of N leaching that arises from farm management and not background leaching that arises even if production does not take