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Analysis of environmental and economic efficiency using a farm population micro-simulation model

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Abstract

New Zealand's success in raising agricultural productivity has been accompanied by higher input use, leading to adverse effects on the environment. Until recently, analysis of farm performance has tended to ignore such negative externalities. The current emphasis on environmental issues has led dairy farmers to target improvements in both environmental performance and productivity. Therefore, measuring the environmental performance of farms and integrating this information into farm productivity calculations should assist in making informed policy decisions which promote sustainable development. However, this is a challenging process since conventional environmental efficiency measures are usually based on simple input and output flows but nitrogen discharge is a complex process affected by climate, pasture composition, cow physiology and geophysical variability. Furthermore, the outdoor pastoral nature of New Zealand farming means that it is difficult to control input and output flows, particularly of nitrogen. We present a novel approach to measure the environmental and economic efficiency of farms, using the Overseer nutrient budget model and spatially micro-simulated virtual population data. The empirical analysis is based on dairy farms in the Karapiro catchment, where nitrogen discharge from dairy farming is a major source of nonpoint pollution.

Keywords: Data Envelopment Analysis; Economic efficiency; Environmental efficiency; Dairy farming; Micro-simulation

1. Modeling environmental performance

New Zealand's success in raising agricultural productivity has been accompanied by higher input use, leading to adverse effects on the environment. Until recently, analysis of dairy farm performance in New Zealand has often ignored undesirable effects on the environment [13,14,17]. The eco efficiency study by Basset Mens et al. [3] provides a notable exception by indentifying farms which were both economically and environmentally efficient. This was achieved by including nitrogen discharges into the analysis of farm production and financial performance. This paper extends this approach and provides separate measures of economic, environmental and joint economic and environmental performance.

The current emphasis on environmental issues has led dairy farmers to target improvements in both environmental performance and productivity. Therefore, measuring the environmental performance of farms and integrating this

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information into farm productivity calculations should allow farmers to benchmark their performance and assist policy makers to make informed decisions which promote sustainable development.

The remainder of this section outlines our use of Data Envelopment Analysis (DEA) and recent approaches to the measurement of environmental performance. We then outline some of the challenges in measuring dairy farm environmental efficiency. In Section 2 we detail the specification of the DEA model and our definitions of four different measures of efficiency (technical, economic, environmental and joint environmental and economic efficiency). This is followed by details of the empirical analysis (Section 3), results, implications and conclusions.

We use Data Envelopment Analysis to analyse the environmental and economic efficiency of dairy farms using a spatially micro-simulated population farm data set and the Overseer nitrogen discharge model. The methodology involves a two stage process; first the Data Envelopment Analysis (DEA) problem is solved, then the efficiency scores from the first stage are regressed on other explanatory variables using the maximum likelihood approach to identify reasons for differences in performance. DEA has been used extensively to analyse environmental efficiency in intensive farming systems [6,10,24,26]. It has the advantage of not requiring assumptions about the functional form of the relationship between inputs and outputs and so avoids restrictions that would distort efficiency measures [5,11]. The approach can, however, be criticised for not accounting for the possible influence of measurement error and other noise in the data [7]. Since a virtual population of farms is used to construct the frontier in this study, it can be considered to be free of sampling error, since efficiency is measured for the whole population not estimated based on a sample.

Our approach to measuring environmental performance involves the incorporation of environmental impact into productivity analysis. Environmental effects are often brought into the model as either undesirable outputs or undesirable inputs. An early application of DEA to agriculture is provided by Reinhard et al. [21]. They treated nitrogen surplus as an environmentally detrimental input when calculating technical efficiency and environmental efficiency. They defined environmental efficiency with input orientation as “the ratio of minimum feasible to observed use of an environmentally detrimental input, conditional on observed levels of the desirable output and the conventional inputs”.

More recently, two novel approaches to assessment of environmental performance based on DEA have been published [2,6]. Asmild and Hougaard calculated environmental and economic efficiency by incorporating the economic output variable along with the nutrient content of the output (the environmental variable) in the output matrix. Economic efficiency was calculated by incorporating the economic variable as output while environmental efficiency incorporated environmental output. A potential problem with this approach results from inclusion of an additional variable (nutrient content of output) when estimating combined economic and environmental efficiency. This is likely to lead to dimensionality and an upward bias in the efficiency estimates.

Coelli et al. [6] quantified the environmental efficiency of Belgian pig farms using the material balance concept by determining the combination of inputs that produces a specified amount of output while minimizing nutrient surplus. Nutrient surplus was calculated as a linear function of inputs and outputs using the material balance concept. Material balance approaches quantify environmental impact in terms of difference between simple input and output flows. These approaches work well for intensive farming systems, e.g. pig finishing, where nutrient inflows and outflows are highly manageable and there are few uncontrollable environmental effects. However neither of these studies explicitly included the influence of geophysical factors on environmental impact.

However, the impact of New Zealand dairy farms on the environment depends on complex interactions between climate, pasture, cow physiology and geophysical parameters. In addition to this, the outdoor, pastoral nature of New Zealand farming means that it is difficult to control input and output flows, particularly of nitrogen. As such, the approach adopted by Coelli et al. [6] would be hard to apply to dairy farming in New Zealand.

The nature of extensive dairy farming means that it is not possible to estimate nitrogen surpluses directly, as nitrogen input and removal are affected by natural processes such as nitrogen fixation and denitrification. Nitrogen fixation by clover depends on factors that affect clover growth and persistence in dairy pastures, including climate, soil fertility, fertilizer use, cultivar selection, pasture establishment, grazing management, and incidence of pests and diseases. As a result, the clover content of pasture changes from year to year.

Biologically fixed nitrogen in clover plants is converted into various forms and excreted into the soil where it is converted to nitrates through ammonification and nitrification. In addition to this, the size of nutrient surpluses is not the only factor affecting the level of damage to water quality, as there are other influences at work as well. These include soil type, topography, animal productivity, climate and livestock management during winter [23].

The measurement of environmental efficiency described in this paper combines the merits of the efficiency measures described by Reinhard et al. [21], Asmild and Hougaard [2] and Coelli et al. [6] in order to develop an appropriate