Developing an Integrated Measure of Farm Performance

Mary Graham

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Agricultural production, by its nature, impacts upon the environment. Performance measurement from the perspective of society should consider the full impact of a productive activity. This paper examines how the use of a biophysical model can assist in developing a farm performance measure inclusive of environmental impacts. Biophysical modelling at the farm level allows for biological, physical, and economic processes to be integrated into a performance measure.

**Key words:** biophysical, environmental impacts, joint production, DairyMod, farm level modelling

1. **Introduction**

Air, soil and water are environmental resources commonly used in economic activities either as an input to the production process, or as an output in the provision of a ‘sink’ for the disposal of waste. Environmental services however are generally not reflected in the market prices paid by producers or consumers for the goods and services produced. Consequently, market signals may distort the allocation of resources. Activities which are detrimental to society, such as those that generate pollution, may be encouraged, while activities which may be beneficial to society, such as fencing off waterways to limit stock access and prevent water pollution, may be under produced.
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Growth of the agriculture sector in the developed economies of the United States, United Kingdom, Europe, and Australia, generally reflects productivity increases resulting from technological change. Improved breeding practices, pasture production and feed supplementation are examples of new and improved technologies widely adopted by farmers that has resulted in increased efficiency and profitability of farm management practices. These technologies also impact the environment. Soil erosion, salinity, the depletion and contamination of aquifers from irrigation and fertilizer represent unintended ‘products’ in many developed agricultural systems arising from widespread adoption and use of a particular technology over time (Archibald 1988). For a discussion of environmental impacts and agriculture see, among others, Carpenter et al. 1998, Jarvis 1999, Pimentel 1999, Powlson 1999, Pretty 1999, Parker 2005, Tisdell 1999, Williams 2005.

Traditionally agricultural performance evaluation has adopted the perspective of the producer, a private individual, and ignores the services provided by, or the impacts on, the environment. See, for example, Ahmad and Bravo-Ureta (1996), Coelli and Battese (1996), Battese and Coelli (1988), Cloutier & Rowley (1993), Cuesta (2000), Dhungana et al. (2004), Fraser and Cordina (1999), Jaforullah and Whiteman (1999), Henderson and Kingwell (2005), Kumbhakar and Hjalmarsson (1993), Kumbhakar et al. (1991), Weersink et al. (1990)

From the perspective of society, when technology interacts with the environment, as it does in agriculture, it is essential that performance measurement considers the full impact of the production process (Antle et al. 2005, Weaver 1996, Weaver et al. 1996).
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Measures of a farm’s performance inclusive of environmental impacts reported in the literature, are limited to studies undertaken of American (see Ball et al. 2001, Ball et al. 2002, Ball et al. 2004) and European dairy and pig farms (see Reinhard et al. 1999, Reinhard and Thijssen 2000, Reinhard et al. 2000, Fernandez et al. 2002 Oude Lansink and Reinhard 2004, Ondersteijn et al. 2005 and Coelli et al. 2007). Analysis of Australian farm performance has not previously been approached from the wider social perspective. A review of the literature shows Australian farm performance analysis to be limited to measures of private productivity and efficiency (see for example, Fraser and Cordina 1999, Kompas and Che 2002, Fraser and Graham 2005 and Kompas and Che 2006).

In all Australian dairy regions, farmers are encouraged by their industry body to consider the environment and integrate environmental management into profitable dairy farming systems (WestVic Dairy 2004). The Department of Sustainability and Environment (DSE), along with the Department of Primary Industry (DPI), collaborate with industry, farmers and local communities to develop and implement sustainable production systems, aimed at the long-term viability of the industry. The Regional Natural Resource Action (2001) for WestVic Dairy, one of Australia’s dairy regions, argues that the drive for increased productivity needs to be harnessed and natural resource management improved by using resources more effectively and in innovative ways (WestVic Dairy 2001).
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A long term goal of the Victorian government as outlined in the recent Green Paper on Land and biodiversity at a time of climate change is for the economy to use ecosystem resources in a more sustainable manner (DSE2008). To achieve such a goal productivity increases need to be achieved without environmental harm and resources need to remain available for future generations. To enable a more informed judgment as to the likely availability of resources for future generations, the use of the environment needs to be included in performance measures.

Models that incorporate environmental impacts are needed to widen performance evaluation to include the environment. Information on the structure of technology and production relationships, including a measure of damage, as well as information on input substitution and changes in the output mix are required if productivity measurement is to reflect the contribution of technology to the growth of the agricultural sector (Archibald 1988).

To capture this information, this paper presents an interdisciplinary approach to measuring dairy farm performance. A dairy system biophysical model that simulates the use of the environment by a farm is integrated with an economic model that determines the level of output achieved with private inputs. The biophysical inputs and the economic inputs measure the aggregate inputs used to produce the output at the farm level. The use of the environment can be location specific and hence the disaggregate level, the farm level, is necessary to capture the heterogeneity of the physical environment and the economic behaviour of farmers (Just and Antle 1990). Farm level analysis allows for the contribution of biological and physical inputs to be identified and integrated with economic processes.
The structure of this paper is as follows. The need for a farm level biophysical model to be used in performance evaluation is examined in Section 2 before an integrated model, composed of economic and biophysical inputs, is developed in Section 3. Section 4 examines the relevance of the biophysical model, DairyMod, to farm performance evaluation. Limitations of the model are examined in Section 5 before some concluding comments on the use of such models in performance evaluation are offered in Section 6.

2. Why is a biophysical model required?

Within the agricultural sector, both private and environmental or public inputs are used in the production process. The sector draws on the environment for inputs such as rainfall and soil, and for the disposal of wastes, such as nutrients from fertiliser application. It directly competes with other industries and households for such resources. If the resources are reduced due to either poor management or use by other industries, agricultural production, in the absence of technical progress, will contract (Tisdell 1999). Alternatively, to maintain the output level, a higher level of private inputs would be required.

Complementarities exist between agriculture and environmental services. Agricultural commodities and environmental services can be regarded as ‘joint products’ in that agriculture relies on the environment, or ecosystem, for example, soil and water, and at the same time agricultural activity impacts on the environment, for example run-off and leaching of nutrients. The relationship between agricultural production and environmental services can be illustrated using an input or an output orientation towards production. An input orientation is illustrated in Figure 1 below.
Output represented by isoquant YY can be produced using different combinations of the conventional input (x) and the environmental input (z). Production at point C, for example, requires more of the conventional input x than does production at point B or at point D. If environmental inputs have no market value, a farmer may freely use as much of the environmental service as desired and produce at a point, such as D. For example, the soil and ground water could be left to absorb excess nitrates from fertilizer applications. Private efficiencies may be pursued at the expense of the environment which provides the ‘free’ input—free at least to the individual user.

If both environmental and conventional inputs are valued equally, the optimal combinations of inputs is at point B, since the ray OA is a minimum distance measure and movements along the ray involves equiproportional reductions in both inputs.

If society places any value on environmental services, even if less than conventional inputs are valued, the optimal social mix could be somewhere to the left of point B, for example at point C. The difference between producing at points B, D and C illustrates the possible divergence that might occur between the private and the socially efficient outcome of dairy farming.

If an output orientation is adopted, the production of the intended agricultural output can be accompanied with the production of the unintended environmental goods or services. Technically the amount used to produce the agricultural output and the
amount used to produce the environmental impact cannot be separated. The relationship becomes increasingly competitive as agricultural production is increased and additional output can only be obtained at the expense of the environment (Fraser and Hone 2001).

In Figure 2 below, using an output orientation, jointness of production is shown by the production possibility frontier (PPF), RST. Initially, at low levels of output, both agricultural production and the environment complement one another, but as agricultural production increases and moves beyond point S, there is competition for resources and any increase in agricultural output occurs at the expense of the environment. The goods are jointly produced over the restricted range, RS. The relationship is, however, not always monotonic. Over some range of production, a reduction of agricultural production intensity can produce an increase in environmental quality, while over other ranges, the opposite may apply (Hodge 2004).

**Figure 2 near here**

The general research strategy for assessing farm performance inclusive of environmental resources has been based on both production function orientations. The different approaches require either quantity or price (shadow or imputed) data, and the method chosen often reflects the data that are available.

Commencing with the work of Pittman (1983), followed by Färe et al. (1989, 1993), Repetto et al. (1996) and Gollop and Swinand (1998), the impact on the environment is treated as an undesirable output. All focus on the pricing of the undesirable output in measuring the performance of the United States agricultural sector. Approaches used to estimate shadow prices include abatement costs, cost of foregone output, and
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marginal damage costs. The selection of an appropriate shadow price is important and influences the performance of production units. However, despite considerable research on selecting the appropriate value, estimates vary considerably (Gollop and Swinand 1998).

To avoid the need for prices, distance functions can be used to incorporate environmental impacts as an output (see for example, Ball et al. 2001, and Färe and Grosskopf 2004), or as an input (see for example, Reinhard et al. 1999, De Koeijer et al. 2002, Ball et al. 2004, and Oude Lansink and Reinhard 2004). Although these studies apply different estimation techniques, the environmental impact is modelled along with other conventional marketed outputs or inputs.

To measure the environmental impact arising from the use of nitrogen fertiliser, a nitrogen surplus can be calculated. Studies of Dutch pig and dairy farms use the materials balance condition to determine the extent to which the environment is used to absorb the nitrogen surplus, the excess fertiliser applied to boost farm production (see Reinhard et al. 1999, Reinhard and Thijssen 2000, Reinhard et al. 2000, Coelli et al. 2007, Drechsler and Watzold 2007, Ebert and Welsch 2007). Materials balance is achieved where the nutrients in the marketed output (y) plus the discharge of nutrients into the environment equals the nutrients in the inputs (x). The nutrient surplus measure, $z \in \mathbb{R}_+$, is calculated using a materials balance equation:

$$z = a'x - b'y$$

where $a$ and $b$ are ($K*1$ and $M*1$) vectors of known non-negative constants.

However, incorporating the environment as an input or as an output in the production technology could be argued to be inconsistent with the materials balance condition. The relationship between the amount of fertiliser applied on any farm and the
environmental consequences may not be as simple as the materials balance condition implies. The excess nutrients indicate the potential that exists for environmental impacts. It does not indicate the damage. The excess nutrients could be used for another on-farm activity. Even if there is no other activity to use the excess nutrients, the actual impact will depend on a range of factors, including soil type, slope of land, fertiliser application rate and timing, closeness of water ways, vegetation cover etc., none of which are necessarily accounted for in the materials balance approach. Biophysical differences between farms, such as soil, vegetation, rainfall etc., are likely to produce different environmental impacts. Just and Antle (1990) claim both agricultural production and environmental impacts depend on highly location specific environmental conditions. Statistically reliable field-specific production data and environmental data make possible measurement of key parameters that are needed to assess performance.

2.1 Farm level modelling

Agricultural production takes place over time and with many interacting sub-systems adding to the complexity of the production process. Within any particular production season, a farmer has a sequence of decisions to make relating to, among others, the quantity and timing of the fertiliser applications, and the cutting of pasture for silage or leaving it for hay. In addition, the agricultural system interacts dynamically with the environment. Each component of the system may be dynamic but if the properties are not integrated dynamically, then the relationship could be described as ‘loose coupling’ (Antle et al. 2005). Performance measures such as productivity are then determined by exogenous biophysical conditions and economic decisions, such as land use and management. Econometric models could perhaps include a measure of
soil quality and climate in their production function. Economic decisions affect environmental outcomes, but environmental changes do not feed back to the economic outcomes.

However, if close coupling characterises the system, the biophysical and economic components of the model interact dynamically. Hence, management decisions impact soil productivity and soil productivity in turn affects management decisions. The use of a biophysical model attempts to capture these dynamics so that the extent of the environmental impact varies with individual farm characteristics – soil type, slope as well as individual farm practices. The underlying biophysical conditions that affect a farmer’s productivity (soil, climate) can then be linked with the economic model so that the system can be judged in terms of economic and environmental performance (Antle et al. 2005).

The interaction of agriculture with the environment means that there will be in any one region a large number of farms emitting waste products. Point source emissions, such as dairy effluent or nutrients in run-off, may be relatively visible while others, for example leaching, may not be so visible and their impact may extend beyond an individual farm. The extent to which agricultural nutrients will be transported across surfaces or in ground depends on farm site characteristic, including soil type and structure, production practices, such as fertiliser application rates, climatic events before and after the application of fertiliser, and the particular environmental characteristics of watersheds that serve the farm (Hall and Hartwig 1978, Eckard 2001). Identification of emissions from diffuse sources becomes difficult if not impossible.
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Farm level modelling enables the interactions between the decision behaviour and the preferences of the farmer to be considered together with the uncertainties existing in the environment and the dynamics of the managed resources (Drechsler and Wätzold 2007). If statistically reliable field specific production and environmental data are available (for example from statistically representative samples of the population) key parameters can be measured with the results providing a more comprehensive measure of the extent to which the environment is used in the production process.

Examples of whole farm modelling analysing the interactions of economic and ecological demands on agricultural land use include the use of the model MODAM, by a research station in Bavaria (Meyer-Aurich 2005). In England, a database for crop treatments and nitrogen (N) loss generated with a weather model, IACR SUNDIAL, was linked to an economic model, FARM-ADAPT, to assess the economic impact of measures to reduce nitrate loss in a root cropping system (Gibbons et al. 2005).

The method of analysis could be extended to a wider group of farms, or to the whole dairy region, or to all dairy regions in the country. The use of catchment-wide or regional models such as the Erosion Productivity Impact Calculator (EPIC), or the Groundwater Loading Effects of Agricultural Management Systems (GLEAMS) would allow the analysis to extend to a wider group of farms or whole dairy regions. Aggregation, necessary for regional models, needs to ensure that the heterogeneity that exists within a region, as well as the non-separability that exists between the environment and the agricultural activity, is fully captured (Wossink et al. 2001).

The following section develops a framework which integrates a biophysical and an economic model at a disaggregate level necessary to capture the heterogeneity of the physical environment and the economic behaviour of farmers. Paddock scale land use
and management is linked through the biophysical model to identify and quantify the biophysical impacts of an economic activity.

3. An integrated model

The interdependence that exists between the agricultural sector and the environment requires a framework that recognises this two-way interaction. Private economic choices relating to inputs and outputs, as well as the effect of these private choices on the biophysical processes, need to be considered.

An integrated model, composed of an economic model involving the private good production process, and a biophysical model describing the biophysical processes, can be developed. Using the notation of Weaver et al. (1996) the model can be expressed as:

\[ G(Y^i, Q^i, X^i, E^i, Z, \theta^i) = 0 \]  

where the superscript \( i \) indicates the variable is associated with the \( i^{th} \) farmer. The output \( Y^i \) is private goods produced and inputs, \( Q^i, X^i, Z, E^i, \theta^i \), include environmental, private, and public or semi-public good inputs. In particular,

- \( Y^i \) is a \( M \times 1 \) vector of private good outputs, (e.g. milk, animal sales)

- \( Q^i \) is a \( J \times 1 \) vector of environmental inputs, (e.g. the environment absorbing nutrients through leaching, run-off)

- \( X^i \) is a \( N \times 1 \) vector of private good variable inputs, (e.g. labour, fertiliser, feed)
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- \( E^i \) is a \( L \times 1 \) vector of environmental effort, defined in relation to the extent of adoption of environmental practices or specific input embodied effort that contributes to the production of the environmental effects, (e.g. the use of effluent ponds on dairy farms, feeding pads for young stock, where such practices contribute to the production of environmental effects)

- \( Z \) is a \( K \times 1 \) vector of public or semi-public good input flows, or environmental conditions, not depleted by contributing to the productivity of output, (e.g. rainfall, slope of the land, etc)

- \( \theta^i \) is a \( J \times 1 \) vector of flows from quasi fixed private factors of production, (e.g. farm buildings, land, etc.).

Because \( Q^i \) and \( Z \) are public or semi-public inputs, the production function involves the direct interaction of private and public goods and, hence, represents a mixed good production function. Private output and inputs can be measured in dollar values (quantity x price) since they are traded on the market, and to measure environmental effects, taking consideration of public or semi public good input flows, a biophysical simulation model of the dairy pasture system can be used (Weaver et al. 1996).

If the public good interaction is ignored, the joint production function takes the form:

\[
F(Y^i, X^i, \theta^i) = 0
\]  
(2)

The incorporation of \( \theta^i \) gives a joint production function but it has no public good interaction, \( Z \) or \( Q \), as is implicit in equation 1. To model environmental effects, the private production function can be combined with an additional process that reflects the biophysical process:
H(Q\textsuperscript{i}, X\textsuperscript{i}, E\textsuperscript{i}, Z, \theta) = 0  \quad (3)

However, combining equations 2 and 3 to evaluate a farm’s performance gives a non-jointness or ‘environmental independence’ to the analysis (Weaver et al. 1996, p. 176). Prices on private inputs are treated independently, as are the combination of private and public inputs.

In contrast, modelling agriculture production as being produced jointly with environmental services brings a ‘holistic approach to the study of farming systems by focusing on the interactions between system components’ (Weatherley et al. 2003, p. 2). If environmentally interactive technologies are being considered, public and quasi-public goods used in the production process need to be considered (Weaver 1998). The environmental effects result from the integration of private good production with biophysical processes (Weaver et al. 1996). Complexity and uncertainty are inherent to the interaction of the environment and the economic system. Using an integrated model allows the behaviour of a complex system to be explained in a more reliable way (van den Bergh et al. 2006).

4. **An example of a biophysical model: DairyMod**

A Victorian-wide project, Best Management Practices for Nitrogen in Intensive Dairy Production Systems, reported in Eckard et al. (2001), aimed to produce guidelines to ‘minimise’ N losses while maintaining dairy pasture productivity, and to evaluate different N cycling models. DairyMod, developed specifically for Australian dairy farming systems, provides the level of detail required to predict the N cycle. The
model, produced through a DRDC (now Dairy Australia\(^1\)) funded research project, commenced in 1998 and has been developed and refined using peer review processes, including the National Dairy Farming Systems Team (NDFS) and workshops with NDFS scientists. In the model, the interaction between management inputs and resource dynamics (water and nutrients) is investigated with a view to identifying efficient, sustainable management strategies (Johnson et al. 2003). Weaver et al. (1996) claims the scale of focus for any model needs to be narrowly defined as the farm field and this can be implemented in DairyMod.

DairyMod provides researchers with a tool to investigate farm management systems operating under different environmental conditions. Rotational grazing management, where the N is supplied either through N fixation by a legume, or as fertiliser, is the main focus of the model. Current knowledge of surface and ground transport of agricultural chemicals indicates the importance of farm site characteristics and the production practices of individual farmers, such as application rates and the timing of applications, in determining the possible environmental impacts. The ability to input information on such farm specific practices, along with local soil and climate data, gives the model the desired flexibility and relevance for application to any dairy pasture located in Australia. The heterogeneity that exists between farms in any one region is recognised (Wossink et al. 2001). An overview of the structure of the model is provided in Figure 3 below and highlights the interrelationships that exist between the components.

**Figure 3 about here**

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1 Dairy Australia was formed in 2000 from a merger of the Dairy Research and Development Corporation, (DRDC) and the Dairy Industry Association, (DIA).
The model combines various inputs including available land, stock, pasture type, supplementary feed in the form of forage and concentrates, fertiliser and climatic information, to produce output in the form of pasture and litres of milk per hectare. The model simulates production in terms of what is technically feasible assuming the farm operates efficiently.

The simulated or modelled pasture growth, as shown in Figure 4, corresponds closely to the growth experienced on field sites from research undertaken at Ellinbank Dairy Research Centre in Gippsland, Victoria. Both modelled and actual pasture growth is most rapid in the spring season when rainfall and temperatures are favourable.

**Figure 4 about here**

Pasture also responds to fertiliser but experiences diminishing returns. As more fertiliser is applied and holding other inputs constant, pasture growth occurs at a decreasing rate. As illustrated in Figure 5, with application rates up to 400 kilograms of nitrogen per hectare per year, (kgN/ha.y), pasture is simulated to increase from 7 tonnes of dry matter weight per hectare (tDM/ha) to between 10.5 and 12.5tDM/ha depending on the N form (urea or nitrate). Increasing the rate of application beyond 400kgN/ha per year will produce much smaller increases. An additional 100knN/ha per year will only produce an additional 1tDM/ha/year of pasture.

**Figure 5 about here**

The second output from the model, milk production, reflects stocking rates and herd management in terms of pasture rotation and the use of supplementary fodder. DairyMod calculates the intake from both pasture and supplementary feeding and uses this intake for the metabolic processes of growth, maintenance, lactation and
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pregnancy (Johnson et al. 2003). Input substitution in terms of pasture, concentrates and forage by individual farms is possible in DairyMod.

DairyMod also simulates water and nutrient flows. Nitrate losses vary with rainfall, the level and source of N inputs, soil characteristics and hence soil N transformation rates, stocking rates, pasture species and growth rate. For example, changing climatic patterns, such as increasing the rainfall received in late winter and early spring, results in the simulated levels of leaching increasing. Figure 6 below illustrates the impact of increasing the rainfall received in late winter through to early spring by an additional 20 and 40 millimetres per annum on the extent of leaching.

**Figure 6 about here**

Water and nutrient flows are also governed by the application rate of N. Research conducted by the Department of Primary Industry (DPI), shows that higher application rates run the risk of increasing leakage of N to groundwater. If the fertiliser application rate is increased from 63 to 80 kgN/ha and then to 100 kg and 200 kgN/ha, making the yearly application of N fertiliser increase from 160 kgN/ha to 800 kgN/ha, the model simulates leaching to increase from 56 kgN/ha to 61 and then 70 kgN/ha, as illustrated in Figure 7 below.

**Figure 7 about here**

In recent years, farmers have been encouraged by DPI field officers to use the rich N resource available from dairy effluent to fertilise summer crops and boost silage regrowth yields. DPI (2006) recommends that fertiliser can be cut back or left off land that has been spread with effluent. In terms of potential environmental impact, the
total N application, rather than the particular form the application takes, is important. Hence, effluent can be assumed to replace a fertiliser application in the model.

Soil type impacts greatly on the level of leaching and run-off. Clay loams result in much less leaching than sandy loams. However, run-off is zero in sandy soils. If rainfall or fertiliser is increased on a sandy loam soil, the amount of leaching is more than double that resulting from a clay loam soil. Increasing late autumn rainfall by 10mm on a sandy soil, while producing zero run-off, results in 171 kgN/hectare leaching compared to 54 kgN/hectare on clay loam soil. Rainfall, fertiliser application rates and soil type all impact on the extent of sandy soil leaching and run-off.

Other factors that influence the extent of leaching include the use of supplementary feed and concentrates, soil temperature, and stocking rates and stocking intensity. Individual farm data for each of these factors can be included in the model.

The output showing the extent of leaching and run-off obtained from the simulation exercise can be combined with data on marketed inputs and outputs to provide an integrated model of the farm production process. As claimed by Weaver et al. (1996) p. 176, ‘the biophysical component of an integrated model provides a useful basis for estimation of the environmental effects based on simulation’. Farm level activity is linked with off-site impacts in an attempt to examine the relationship between land use and the environment. The biophysical and the economic processes of a farm’s production system are integrated in one model from which to derive a wider social measure of performance.

The social production model can be represented as:

\[ Y_i = f(X_i, K_i, Z) \]  

(4)
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Where for all farms indexed with a subscript $i$,

- $Y_i$ represents the output produced in the form of milk production, plus the value of stock and roughage produced and sold, and
- $X_i$ represents variable inputs such as labour, fodder, fertiliser
- $K_i$ represents capital inputs such as the dairy shed, farm machinery etc
- $Z$ represents the environmental input.

Data relating to the first three variables are commonly reported in ABARE farm surveys. Individual farm level data is required to be used in the simulation exercise to derive the figure for leaching and run-off which can be used to show the extent to which the environment is being used in the production process.

The integrated production model can be used to provide estimates of productivity growth as well as estimates of technical efficiency from both a private and a social perspective, using either parametric or non-parametric techniques. Both the Malmquist productivity index and the Luenberger productivity indicator are commonly used measures of productivity growth, efficiency and technical change both with, and without, environmental impacts (see for example, Färe et al. 1994, Chambers et al. 1996, Tauer 1998, Ball et al. 2001, Ball et al. 2004, Färe & Grosskopf 2004, Kwon & Lee 2004, and Newman & Matthews 2007). A comparison of the conventional Malmquist index with the environmentally sensitive Malmquist index highlights the extent to which a farmer’s private productivity performance differs from productivity performance when a wider social perspective is adopted (see Graham 2007)
5. Limitations of the biophysical model at the farm level

While the model is useful in determining the environmental impacts arising from the productive activity of each farm, there are some limitations, relating mainly to the application of nutrients. The number of fertiliser applications is limited to four in any one year and in calculating the amount spread in any one application, there is a need to ensure that no more than the recommended application of 200 kgN/ha is spread in one year. Effluent cannot be treated separately to fertiliser applications.

It is also acknowledged that rainwater and water from yard washing add to the volume of effluent created in the dairy and to include these variables would entail measuring the yard and also the amount of rainfall received in any one year. This may not always be possible.

Feed pads are acknowledged as an important source of nutrients and the variation between feed pads is high, making it difficult to factor their contribution into any analysis. Dung and urine patches in paddocks and laneways used to access the dairy are other sources of nutrients which are also difficult to take into account.

While a figure for the extent of leaching and run-off can be derived from the biophysical simulation model and included with the economic model in estimating a farm’s performance, the level of actual leaching is not as important as the soil type and the extent of travel from source to the water body (Skop and Schou 1999). Individual soil types are required in DairyMod and are reflected in the extent of leaching predicted. The decay processes however include processes that occur from the time nitrate is leached from the plant root zone and until it reappears in the stream. Hence the longer it takes for nitrate to reach the water body, the more nitrates that can be removed by denitrification which will control the nitrate concentration in
soil solution, or retained by accumulation in biomass or sediment. The location of an individual farm, and in particular its proximity to waterways, is significant when examining the wider environmental factors, and in the selection of appropriate policies to protect the environment. The amount of nitrogen leaching and run-off, obtained from Dairy Mod, needs to be modified depending on the closeness of waterways and the extent of vegetation cover on the riparian zones.

Despite such limitations, the model enables biophysical and economic data to be integrated for performance evaluation. Being dependent on site specific soil and climate conditions the integrated assessment model can simulate behaviour in a way that is consistent with established scientific understanding. Environmental impacts are acknowledged to be highly location specific and reflect local conditions. The reliance of the model on farm level data for explaining spatial variation could be argued to limit its usefulness.

6. Conclusion

The aim of this paper has been to demonstrate the need for economic analysis, particularly in relation to agricultural production, to extend beyond the traditional measures and produce performance measures that more closely reflect the expectations of society presented to the farming community. The reliance of the agricultural sector on the environment should be sufficient to ensure environmental impacts are included in performance measures. However, traditional performance measures, using only marketed inputs and outputs, tend to dominate the literature on Australian agriculture performance. Although the scientific community argues for, and DPI extension activities focus on, the need to consider environmental consequences resulting from agricultural practices, the impact of environmental
practices on measured farm performance tends to be ignored. The science and economic disciplines need to work together. Data obtained by scientists need to be combined with economic statistics on marketed output and inputs such as production levels, cost of inputs and prices received for output, to undertake a more comprehensive performance analysis. By being able to quantify the performance of individual farms when such variables are included in an analysis, farmers may view the selection and adoption of appropriate farm management practices to minimise negative environmental impacts more favourably.

An understanding of the biophysical processes is critical to any performance analysis of an agricultural sector. Biophysical modelling allows for the integration of the economic and science disciplines to examine the complex linkages that exist between producer behaviour and the physical and biological dimensions of a farming system. By focusing on the interactions between system components, modelling brings a holistic approach to performance analysis (Weatherley et al. 2003). Environmental effects are a result of integrating the private good production processes with the biophysical processes. The environmental input needs to reflect as closely as possible the public resource that is being used. Using detailed farm level data, integrating the two disciplines in performance evaluation provides a comprehensive analysis.

Comprehensive databases containing information on soil types, land use, livestock, N surplus etc. are collected for some European countries, notably Denmark and the Netherlands. Such data bases provide a rich source of data for analysis of farm performance (see for example, Reinhard et al. 1999, Skop and Schou 1999, Fernandez et al. 2002, and Ondersteijn et al. 2005). A similar database is needed for the Australian Dairy Industry to enable quantitative analysis of farm performance to
extend to the wider social context. Farm level data is required since farm site characteristics and production practices in relation to surface and ground water transport of chemicals are important.

To obtain the required comprehensive data may be difficult, but with the use of biophysical models, simulated data can be obtained and used in modelling agricultural practices or in designing agricultural-environmental policies. Some effort towards a more holistic approach is required.
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Figure 1: Output with conventional and environmental inputs
Figure 2: The agricultural-environment relationship
Figure 3: Overview of the structure of the dairy pasture system model ‘DairyMod’

Figure 4: Modelled average monthly pasture growth rates

(Source: Eckard et al. 2005)
Figure 5: Modelled annual yield response

(Source: Eckard et al. 2005.)
Figure 6: The impact of increased rainfall on leaching
Figure 7: The impact of increasing the rate of fertiliser application