SUSTAINABILITY: MEANING AND MEASUREMENT WITH APPLICATION TO AGRICULTURE

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1.0 INTRODUCTION

The widespread adoption of sustainability gives rise to the need to clearly define the concept, as well as identifying the institutional structures (e.g., markets, government intervention) where sustainable resource use might occur (Godden 2004). While being a difficult concept to define, sustainability is also something that is not easily measurable, and the aim of this paper is to present a conceptual framework that could be used to quantify sustainability at the farm level from the perspective of social economic efficiency. The aim is to provide a more complete measure, encompassing social, economic and environmental factors, than is provided by many of the existing sustainability indicators. By including both private and social impacts, with application to the agricultural sector, a more complete measure of sustainability can be derived.

In Australia, while the lack of water and nutrients can be a constraint on agricultural productivity, water and nutrients are also a cause of much of the land degradation that has occurred at different times and places (Williams 2005). Much of agriculture has become more intensive, and the environmental consequences of these changes can be widespread and include declining water and soil quality, increased weeds and greenhouse gas emissions, and loss of bio-diversity. Sustainable farming, to be discussed later, requires the current magnitude of water, nutrients and energy flows to match those that evolved to suit the landscape at both the farm, catchment, regional and national level.

This paper focuses on the production system at the farm level where farm level activity, and in particular, dairy farm activity, will be linked with offsite impacts in an attempt to examine the relationship between land use and the environment. Biophysical processes need to be integrated with the economic aspects of the agricultural production system to present a clearer picture of the sustainability of the dairy farm system. Often environmental and production performance are seen as being in conflict but if efficiency in the use of inputs can be improved, both can benefit. The socially efficient use of inputs, including polluting inputs, is a necessary but not sufficient condition for sustainability.

This paper is organized as follows. In Section 2, the concept of sustainability and the interconnectedness of social, environmental and economic activities are discussed. In Section 3, the relationship between sustainability and agriculture is examined while in Section 4, production efficiency theory, and in particular, social economic efficiency as a measure of incorporating environmental impacts with economic analysis is introduced. Finally concluding comments and direction of further research are discussed in Section 5.
2.0 THE CONCEPT OF SUSTAINABILITY

Sustainability and sustainable development has a dominant position in the environmental economics and ecology literature. The most quoted definition of sustainable development is that proposed by the World Commission on Environment and Development, (WCED), and reported in the Bruntland Report 1987. Sustainable development is “development that meets the needs of the present without compromising the ability of future generations to meet their own needs.” (WCED 1987, p. 8)

The definition constitutes a normative judgment about welfare of those living in the future relative to those living in the present. It is an “ethical commitment to the welfare of future generations…”, and stresses “…the importance of access to resources and the distribution of costs and benefits” (Castle et al. 1996, p.476). Solow (2000), in presenting the economist’s perspective on sustainability, focuses on the moral obligation to future generations, rather than the economic or ecological obligation. Hence, sustainability requires a process of change in which resource use, the direction of investment, technology, and institutional change are made consistent with future as well as present needs. In economic terms it means future generations should be entitled to at least the same level of economic opportunities, and thus at least the same level of economic well-being, as is currently available to present generations. This could be expressed in the terms of Pezzey (1989) as per capita well-being or utility, not declining over time.

Economic systems at all levels – farm, communities and national economies - rely in part on the services provided from the total stock of capital. It is both the total stock and the composition of capital that determines the range of economic opportunities and well-being, both now and in the future. What is important is that the capacity of capital to produce utility does not decline (Webster, 1999).

Building upon neoclassical foundations (Solow 1992), recent growth theories recognize that aggregate capital, K, consists of manmade or physical capital, Km, plus natural or environmental capital, Kn, plus human capital, or the knowledge people possess, Kh, and social capital, the people and their networks, Ks, (Pretty 1999, Webster 1999), such that

\[ K = Km + Kn + Kh + Ks \]

Man-made capital (Km) refers to infrastructure – plant and equipment, buildings, roads etc.- used in the process of production and consumption. Natural capital refers to nature’s goods and services and contributes to the process, for example, as a source for raw materials such as oil used in manufacturing processes, and as a “sink” for wastes. Human capital comprises the stock of health, education, skill and knowledge of individuals. Social capital is a more recent concept and refers to the social relationships that engender trust, tolerance and honesty between individuals, groups etc. for example, cooperation in “land-care”\(^1\) groups, the establishment of which has reduced land degradation in many parts of Australia.

\(^1\) Landcare is an Australian partnership between the community, government and business to ‘do something practical’ about protecting and repairing the environment. (Landcare Australia, 2006)
It is the stock of capital that determines in part the full range of economic opportunities, and thus well-being, available to both present and future generations. The composition of the stock highlights the need to consider the consequences if there is rapid accumulation of one type of capital, for example, physical and/or human capital at the expense of excessive depletion and/or degradation of another, for example, natural capital. Can one form of capital be substituted for another? Techniques of production differ in proportions of capital used. Society needs to decide how best to use its total capital stock today to increase current economic activities and well-being and how much it needs to save or accumulate for tomorrow and ultimately the well-being of future generations. The mix of capital (that is, manufactured and natural) determines in part the level of utility for society on a yearly basis.

Sustainability requires the aggregate stock of capital, and its capacity to produce non-declining utility from one period to another, be at least maintained over time. It is the capacity to create well-being, rather than a particular capital item or natural resource that is important (Solow 2000). Technological change, the degree of which is uncertain, and population growth will both impact upon and modify the stock of capital. Technological change provides alternative capital resources which could be substituted for the non-renewable resources used up, while rapid population growth rates, although potentially expanding the stock of human capital, places pressure on resources, particularly in the third world.

Many researchers (Costanza 1991, Goodland & Daly 1996, Goodland 1997, Gibbon and Jakobsson 1999) sub-divide sustainability into three aspects: environmental, economic and social. Environmental sustainability is defined as the maintenance of natural capital, that is, the stock of environmental assets which provide useful goods and services (Goodland 1997 cited in Gibbon & Jakobsson). Environmental sustainability refers to protecting the sources of raw materials used for human needs and ensuring that the sinks for human wastes are not exceeded (Goodland & Daly 1996). Social sustainability refers to community participation and strong civil society. Economic sustainability is defined as “maintenance of capital” or keeping capital stock in tack (Goodland & Daly 1996). Capital stock is commonly valued in monetary terms and the valuation of natural capital – the services provided by the environment – presents some difficulties since such goods are not often sold on the market and hence have no prices to use for valuation.

A key issue in the debate about the compatibility of continued economic growth and the different forms of sustainability, particularly, environmental sustainability, is the extent to which natural capital can be substituted for manufactured capital and technological advances and which components of natural capital are non substitutable due to their unique contribution to welfare.

The capacity to substitute other forms of capital for natural capital in order to maintain utility as natural capital is depleted or degraded is a fundamental issue. What is important is the ability of capital, both natural and social, to provide the desired welfare streams over different time periods (Toman et al. 1995). However substitution
goes beyond the substitution of human and physical or built capital. It requires the
ability to offset the natural environment’s reduced capacity to provide waste
absorption, ecological system maintenance and aesthetic possibilities. If substitution
is possible, and, provided savings are sufficient to generate investment, sustainable
welfare paths are possible. However, if substitution possibilities are limited then
concern with fairness and equity over time give rise to a need for safeguarding natural
capital (Toman et al., 1995).

If we emphasize the preservation of “adequate” natural capital service flows, the
concepts of “weak” and ‘strong” sustainability can be used (Toman et al p144). Pearce
and Atkinson (1993) interpret these terms such that if natural capital and other capital
are substitutable, then the weak sustainability criteria can be applied, but if there are
limits on substitution, the strong sustainability criterion of preserving natural capital
may be appropriate. Barbier et al. (1990) allow some substitutability between the
different forms of capital when they define strong sustainability as requiring net
damages to environmental capital be non positive along the whole time path of
exploitation, while weak sustainability requires only that the present value of damages
be non positive. Essentially if we accept that the total stock of capital, both man-made
and natural, that is passed on to future generations is no less than that which was
inherited by that generation, weak sustainability is acceptable. However, if
substitution between man-made and natural capital is not possible, giving rise to the
need to protect natural capital, the concept of strong sustainability is appropriate.

According to Welford (1995), the achievement of sustainability depends upon three
closely connected issues and each need to be addressed by industry. Firstly, the
environment must be treated as an integral part of the economic process and not
treated as a free good. Prices, or shadow prices, are commonly used to value goods
and where goods are not traded on the market and hence prices are not available, the
service provided by such resources must not go unrecognized. Good economic
management requires all inputs and outputs, including environmental services, to be
fully valued and allocated among competing goals to maximize welfare. Secondly,
equity, both within and between countries, needs to be pursued. Third, in order to
consider intergenerational aspects, longer term planning horizons are necessary.

The above principles highlight the interconnectedness of social, environmental and
economic activity at all levels, and why sustainability as a concept, has great appeal
with regard to environmental and resource management. Sustainability is a dynamic
process and requires sub-systems be considered in the context of larger systems of
which they are a part. Sustainability also requires interdisciplinary understanding and
cooperation. Economists must learn the ecosystem rules and biologists must learn
how markets operate (Kohn et al., 1999). Agriculture, as well as forestry and fishing
are all part of larger ecosystems. Sub-systems can be sustained for a long time if
resources either from the larger system or from some external source are used to help
sustain them. Technology, social expectations and knowledge of ecosystem behaviour
change over time, and hence we need to develop techniques of production and
institutions that provide for adaptation and change.

Hence, while sustainability is not something that can be easily measured, it presents,
as indicated above and discussed in Solow (2000), a moral obligation to ensure future
generations have the capacity to be as well off as the current generation. Decisions on
investment, conservation and resource use today are important in achieving a sustainable outcome and the economist can play a useful role in directing attention to the exogenous forces that influence the performance of any sector and to compare different practices in protecting resource endowments for future generations (Castle, 1996).

The approach adopted in this paper is to allow for some substitution of resources so that the capacity of capital to create well being is not depleted. At the farm level, a farmer wants to “sustain the flow of utility to his/her family” (Webster 1999, p.374), and will allocate the capital at their disposal to achieve this objective. The environment in which the farmer operates is also shaped by natural, social, political and economic considerations, and with new scientific knowledge being applied, and technological change occurring, substitution possibilities in farming practices can’t be ignored. Webster (1999), claims that if strong sustainability were to be imposed at a farm level, “major shifts in social objectives amongst farmers” would be required (Webster, 1999, p373).

3. SUSTAINABILITY AND AGRICULTURE

Agriculture, like many other industries, draws on the environment both as a source of inputs, such as water and soil, and as a sink for disposal of wastes, such as nutrients from fertilizer application. It is in competition with other industries and households for resources and if resources are reduced, due to either unsustainable use, poor management, or use by other industries, agricultural production, in the absence of technical progress, will be less (Tisdell, 1999, p.51).

*Figure 1: Environment and Economy: Interdependence between the natural resource base and economic activity.*

Agriculture is claimed to be “the most critical production activity and one of the most vulnerable to mismanagement and the effects of global environmental change” (Kohn et al. 1999, p7). Modern agriculture has been successful in increasing output over
many decades. However, this output has been produced at a cost to many non-renewable resources such as soil and water (Williams 2005). The challenge is to find ways of delivering increased output, without degrading the capital base, which includes social, environmental and economic assets. The full impact of the productive activity on all resources needs to be measured.

Sustainability, as already examine, is a complex concept and with different meanings to different people. Pretty (1995) claims, sustainable agriculture is more a “process of learning”, incorporating innovations and change over time, rather than a specific farming strategy. Success depends not just on the motivations, skills and knowledge of individual farms, but on action taken by groups and communities as a whole as illustrate by the shaded area in Fig.2 below.

**Figure 2: Conditions for Sustainable Agriculture**

The skills of the farmer, incorporating resource conserving technologies, together with local communities and supportive government policies, (i.e. enabling external institutions) all need to work together to promote sustainable agriculture. Natural resource use and management needs to be integrated in a “whole farm system” approach and not treated separately from production and profit. Being highly dependent on the biosphere and living resources, any analysis of agricultural sustainability calls for a holistic approach, where all three dimensions – economic, social and biophysical –are considered (Tisdell 1999).

Farmers are ultimately the people who control the means to influence and achieve more sustainable land use practices. The knowledge and skill acquired over many years is important to understanding the resilience of the system and the prospects for long term viability. In the words of a local farmer from S.W.Victoria, Australia,
“sustainable agriculture is combining a healthy environment with a profitable business and happy people” (Van de Wouw 2005).

Lack of sustainability of farm production can arise from factors internal or external to the farm(s). Endogenous sources of agricultural unsustainability may reflect a high rate of discount being applied, error of judgment or impatience on the part of the farmer shortening the horizon for decision making (Tisdell, 1999, p39). Generally, if there is reasonable mobility enabling the farmer to easily change activities, and/or a perception of a large stock of natural resources, sustainable agricultural practices are less likely to be adopted (Tisdell 1999, p40).

Unsustainability may also occur for reasons exogenous to an individual farmer, such as lack of property rights as in the case of public goods and open access resources such as waterways. High rates of fertilizer application or high stocking rates producing excess manure can give rise to leaching of phosphorous and nitrogen and can result in eutrophication of waterways. In addition, ignorance and government failure can generate economic unsustainability. Neoclassical theory argues that profit is the driving force in the economy and this may not result in long term sustainability of environmental resources or production. The desire to make short term profits, reflecting a farmer’s short term horizon, or where there is a lack of property rights, such as with open access resources, could result in natural resources being exploited or even destroyed, with no substitutes being developed.

Such unsustainable practices develop when we undervalue, or value at zero cost, capital, particularly natural and social capital. The tendency is to over harvest, or over use, such goods. Why should farmers worry about fertilizer leaking into groundwater or the extent of biodiversity on their land? An individual farmer may attach some value to “sustainability” goods such as for example, clean water, but is unlikely to place a value at the “socially optimum level” without some regulation (Webster, 1999). Farmers have their own goals and can’t be expected to automatically consider “higher level goals” (Webster, 1999, p.376) when deciding on appropriate farm practices and/or on the adoption of new technology.

Costs associated with nutrients in the waterways, or the lack of biodiversity, are borne by the whole society and the ecosystem, not the producer whose activity gives rise to the costs (Pretty. 1999). Hence the measure of sustainability needs to be determined from this wider perspective, rather than at the individual farm level. Farming practices, will only be judged sustainable if the practices are economically viable, as well as being socially acceptable and biophysically sustainable as shown by the shaded area in Fig.4 below (Tisdell, 1999, p50).
In the remaining sections of this paper, attention will focus on how we might measure the performance of farms, and in particular, dairy farms, in terms of being sustainable. Information is available on the possible environmental consequences or impacts of farming activities at the local, regional and national level. However, we need to be able to measure the impacts so that a more complete picture can be developed. A proposed method of measurement, using an inter-disciplinary approach incorporating a biophysical and an economic model is discussed in the following section. Biophysical models coupled with economic models can be used to examine the explicit relationship that exists between land use and the environment. The integration of both economic and biophysical models provides more reliable information on the interactions between the economy and the environment and assists in the formulation of policies on land use sustainability. Farm level activities can then be linked to catchment, regional and national environmental outcomes.

4. **EFFICIENCY ANALYSIS AT A FARM LEVEL**

A farmer’s aim is to allocate resources so that utility to his/her family is maximized. Production theory can be used to measure the performance of farms. Economic efficiency is a key measure of the economic performance of any industry, but to be meaningful in a policy context, both market and non marketed flows need to be included. The aim of the remaining section of this paper is to show how traditional efficiency analysis can be extended to include the environmental performance of the agricultural activity and give a fuller assessment of the farm’s performance.
The everyday meaning of the term “efficiency” is a situation where no resources are wasted. Efficiency consists of both technical, which refers to the ability of a farm to produce maximum output from a given set of inputs, and allocative efficiency, which refers to the ability of a farm to optimise on the use of inputs given their respective prices. Allocative efficiency is achieved by selecting inputs to produce a given output mix at minimum cost, or to maximize output with given inputs at minimum cost. The product of technical and allocative efficiency provides a measure of economic efficiency. Profit will be maximized when the highest level of economic efficiency, given the resource constraints, is attained. Both of these efficiency measures relate to the production of goods and have a long tradition of being measured (Farrell, 1957, Fare et al. 1989, 1993, Pittman 1983, Coelli et al. 1998).

In a market economy the price mechanism provides the incentives that guide the allocation of resources to their highest value uses. Environmental resources are typically not marketed and with no price, the information that guides the allocation of environmental resources is thus missing, making it difficult to convert the resources to economic value terms (Ball, Lovell et al. 2004). There is some debate about how environmental impacts should be incorporated, but nevertheless it is important to include environmental resources (inputs), and environmental impacts (outputs), as well as marketed activities, in any performance analysis, whether focusing on an individual farm or at a regional level.

The literature on efficiency measurement is mainly based on physical inputs and outputs. The general research strategy has been to consider environmental effects as undesirable outputs and to recalculate technical efficiency accounting for these undesirable environmental effects, (eg. Pittman 1983, Fare 1989, 1993 and Tyteca 1996). More recently, Reinhard et al. (1999, 2002) and DeKoeijer et al. (2002), model environmental effects as conventional inputs, and derive separate estimates for technical and environmental efficiency. Environmental efficiency, a more recent measure, is based on the environmental impacts of polluting inputs (Reinhard et al. 1999, DeKoeijer et al. 2002).

Dairy farms have a high turnover of nutrients through inputs such as fertiliser and feeds and outputs of products (milk, calves) and wastes. A nitrogen budget, showing how all off-farm and on-farm nitrogen inputs are allocated between on-farm production, and on-farm and off-farm disposal, has been used in studies in the Netherlands examining environmental efficiency (Reinhard et al. 1999, 2002 and DeKoeijer et al. 2002). Does the inclusion of a detrimental input, or a detrimental output, in the measurement of efficiency really indicate anything? Is it not to be expected that a farmer will apply whatever input is necessary to obtain the maximum output from the inputs or produce an output at least cost to maximize profit? Is it fair to expect farmers to consider the wider social impact of their agricultural pursuits?

If we consider dairy farmers, why should a dairy farmer worry about the conditions of the rivers, or the stock of biodiversity that is on their land? The costs of such losses are not borne by the individual farmer but rather by the whole society or ecosystem (Pretty 1999). Conflicts are likely to arise between the farmer’s aim to maximize yield and society’s aim to utility as a result of the different types of capital being used in the production process. Natural capital, due to its public good characteristics, tends to be undervalued by an individual and hence overused. As mentioned above, what may be
regarded as sustainable at the individual farm level may, when all farms are considered, be unsustainable at the community or national level. The nutrients that are leached or transported in run-off from one farm may have no or only a small impact on the quality of water in nearby waterways, but if the processes occurs on all farms along a waterway the quality of water will deteriorate rapidly and impact greatly on the ecosystem. This wider impact needs to be considered in any performance measurement. Hence in examining the sustainability of agricultural production at the farm level, there is a need to characterize the system in both bio-physical and economic terms.

4.1 Incorporating Environmental Impacts

Following Weaver et al. (1996), a systems perspective where technology interacts with private and environmental inputs jointly to produce private and environmental outputs, that is joint output, is developed. The level of private output (milk in the case of dairy farming), is partly dependent on public or quasi-public output, such as environmental flows (nutrient flows in surface and ground water) as well as a vector of traditional inputs, such as labour, feed, fertilizer, plus other unpaid environmental inputs such as rainfall, slope of land. Hence an integrated model to examine the environmental impact of farming can be composed of an economic model, involving the private good production process, and the biophysical models, describing the biophysical processes to give us the following model, using the notation of Weaver (1996):

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

where output is both private goods and environmental goods and inputs includes the public and environmental, as well as private good inputs. In particular,

- \( Y^i \) is a M * 1 vector of private good outputs, (e.g. milk,
- \( Q^i \) is a J * 1 vector of environmental effects, (e.g. water quality, soil quality), which could be depleted by contributing to the production process
- \( X^i \) is a vector of private good variable inputs, (e.g. labour, fertilizer, feed),
- \( E^i \) is a L * 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. effluent ponds, feeding pads).
- \( Z \) is a K * 1 vector of public good input flows or environmental conditions not depleted by contributing to the productivity of output, (e.g. rainfall, aspect of the land, etc.)
- \( \theta^i \) is a J * 1 vector of flows from quasi fixed private factors of production, (e.g. dairy shed, land, etc.).

Because \( Q^i \) and \( Z \) are public goods, the production function involves the direct interaction of private and public goods and hence represents a public good production function. Private output and inputs can be measured in dollar values (quantity * price) since they are traded on the market, and to measure environmental effects,
taking consideration of public good input flows, a biophysical simulation model of the dairy pasture system, such as DairyMod\(^2\), can be used.

DairyMod is a simulation model developed for Australian dairy systems and includes modules for pasture growth and utilization by grazing animals, animal physiology, water and nutrient dynamics, as well as a range of options for pasture management, irrigation and fertilizer application. There are multiple subdivisions, each with its own soil types, nutrient status, pasture species, fertilizer and irrigation management. The model has the potential to explore combinations of factors that relate to individual farms, such as stock and fertilizer management options, pasture species, irrigation scheduling and so forth, across a range of locations. Different soil types, nutrient status, pasture species, fertilizer and irrigation management strategies can be incorporated, giving the model considerable scope to explore different management practices on pasture utilisation, and milk production.

DairyMod incorporates the complex interactions among soil characteristics and the contribution of weather factors into the possibility of leaching and run-off which can be used as proxies for the environmental consequences of the dairying activity. The relationship between the physical environment and the farming practice is embodied in the model. For example, the model can be used to estimate the extent of nitrate losses in terms of leaching, denitrification or volatisation, as well as the extent of run-off from the individual dairy farms under study. Nitrogen in the form of nitrate is very mobile and is easily leached in drainage water, whereas leaching of phosphorus is usually much less because of the filtering effect of soil. Consequently the major concern with respect to groundwater quality is nitrate and with increasing use of fertiliser on dairy farms, the question that must be asked is the impact of this trend on ground water quality. Skop and Schou (1999), make the point that what is important is not the actual leaching but rather the loadings, which differ from the leaching depending on the extent of travel from source to the water body and the soil type. The decay processes 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 recipient, i.e. the water body, the more nitrate that can be removed by denitrification (process that controls the nitrate concentration in soil solution) or retained by accumulation in biomass or sediment. The amount of nitrogen leaching and run-off, obtained from Dairy Mod for any one farm, needs to be modified depending on the closeness of waterways and the extent of vegetation cover on the riparian zones.

4.2 Method of Analysis

The modeling techniques employed to measure a farm’s performance are based on an interpretation of the “production frontier” approach suggested by Farrell (1957). Interpretations of the frontier can be categorized as either parametric or non-parametric. The parametric approach involves the use of stochastic frontier analysis

\(^2\) An overview of DairyMod, along with some applications, is given in Johnson, I R. et al. (2003). DairyMod: Optimising Productivity and Utilisation of Dairy Pastures Through Grazing Management, is available at <www.imj.com.au>. It is a research dairy pasture simulation model and the project is funded by DRDC, now Dairy Australia, and the University of Melbourne, Australia.
(SFA), the econometric approach, while data envelopment analysis (DEA) is a non-parametric approach based on linear programming. In addition, index numbers are commonly used.

The SFA method is preferred by some researchers because it is stochastic and so is able to distinguish the effects of random noise from productive inefficiency and accommodates formal statistical tests. The model assumes an error term that has two additive components: a symmetric component which accounts for pure random factors, weather, luck etc, and a one sided component which captures the effects of inefficiency relative to the frontier (Ahmad & Bravo-Ureta (1996) and Coelli & Battese (1996). However, the functional form of the production function and the distribution assumptions of the two error terms must be explicitly specified, opening the possibility of misspecification and thus biased estimates of inefficiency. In addition, SFA is limited in its application when producers undertake a number of different activities, or the one activity results in the joint production of output, because it can only accommodate a single aggregated output.

The non-parametric approach is chosen by other researchers because of its ability to accommodate multiple outputs and because it is less prone to specification error. However, in contrast to the SFA approach, DEA fails to distinguish the effects of random noise from inefficiency and attributes all deviations from the frontier to productive inefficiency.

In agriculture economic literature, SFA has generally been preferred for a number of reasons. The role of weather, pests, fires, etc. in agricultural production makes the reliance that all deviations from the frontier are associated with inefficiency, as assumed in DEA, difficult to accept. It could also be argued that there is a high probability that the data is subject to error, given that many farms are still family owned and operated and accurate record keeping may not be a top priority, although this attitude is changing as farms increase in size and profits are challenged with increasing costs and decreasing prices, forcing the need to accurate record keeping.


Productivity indexes, based on distance functions which can handle multiple outputs and inputs, are also used to measure productivity change and one that is of particular relevance for analysing non-marketed environmental impacts is the Malmquist index. The Malmquist index uses quantity rather than price information, and although commonly used to calculate productivity growth and occasionally shadow prices, it can be used to incorporate environmental impacts, provided the impacts are quantifiable, into a measurement of social economic efficiency (Ball, Lovell et al.13
Information on the structure of production replaces price information, and it can be based on either an input or an output distance function.

The Malmquist productivity index, as proposed by (Fare, Grosskopf et al. 1989), is based on Shephard’s output distance function which inherits the properties assumed for the technology and treats all output, whether “good” or “bad” the same. Hence any increase in ‘good” output is accompanied by an increase in “bad”. To accommodate for “bad” outputs, (Ball et al. 2001) suggest another index, the Malmquist-Luenberger productivity index. Bad output, b, need not be changed proportional with increases in good output, y. The direction of the output vector is (y, -b), rather than (y,b) as with the traditional Malmquist productivity index. An index with a value greater than one indicates an improvement in productivity.

Alternatively, Ball et al. (2004) claim that although some reduction in the environmental impact may be possible, complete elimination is unlikely given the constraints imposed by the production technology. In addition, Ball et al., (2004) claim that the environment can be regarded as a receptacle into which producers can dispose of their detrimental environmental by products. Strong disposability would then be an appropriate assumption and the environmental impact should be treated as an input and develop a Malmquist environmental productivity index based on input distance functions.

Ball et al. (2001, 2004) use mathematical programming techniques to calculate both the conventional and the environmentally sensitive Malmquist productivity indexes for US agriculture over the period 1960-1993 and 1960-1996. A similar approach is intended is to be applied to a small data set covering dairy farms in S.W. Victoria Australia, over the period 1996-2000, in an attempt to derive a measure of the impact of the agricultural activity. The Australian dairy industry, a competitor on the international market as well as producing for the domestic market, has gone through a number of changes in recent times. Farms unable to maintain profitability have left the industry and the remaining farms have increased both the size and the intensity of their operations. Purchased inputs and stock rates have both increased and an analysis of the full impact of these changes is of interest to industry groups and the wider community. An efficient farm will be one that is making the best use of its resources. It does not necessarily imply sustainability. However, by being able to point to those farms that are not efficient, and by identifying explanatory factors which may help account for unsustainability, appropriate farm management practice to minimize negative environmental impacts can be suggested to farmers by farm extension officers or other project workers. For example, adoption by the farmer of more accurate methods of identifying fertiliser needs, such as soil tests, combined with more precise application techniques, will reduce costs and therefore improve profits while also reducing N losses and the extent leaching and run-off deteriorate the quality of ground and surface water sources. The fencing off of waterways and revegetation of the riparian zone will increase the decay process and reduce the amount of nitrate reaching water bodies. Farmers, working with other farmers in focus groups or with the assistance of farm extension officers or other project workers, will be able to monitor their environmental as well as their financial performance. Both the individual farmer’s utility and that of society will be improved as a result of such action. From a social viewpoint this must be beneficial.
5. CONCLUSION

Agricultural systems are complex and are viewed differently by different people, depending on the individual’s perspective. Agriculture sustainability has generally been questioned in relation to general concerns for the environment, the use of non-renewable energy in production, the dependence on external inputs and management of all natural resources. The intensity of resource use has, and will continue to change; hence we need a better understanding of the interdependence of natural resources, livestock and the environment. An inter-disciplinary approach to the management of agricultural resources in an environmental friendly and sustainable way is necessary.

Farmers are the people who undertake land use practices and have the ability to influence and achieve more sustainable outcomes. An understanding of the farmer’s decision process is necessary as well as ensuring decisions are made on the basis of sound and accurate scientific information and full knowledge of the consequences. Farm level sustainability needs to be determined at the farm level and policy needs to focus on providing incentives for farmers to explore and exploit their own specific circumstances (Webster 1999). If scientists work with resource users and others concerned with the management of resources, for example, the farmers, a sustainable outcome is possible. Ecological knowledge needs to be combined with agricultural technologies in deciding upon any agricultural practice. Sustainability requires the resource base provides for future generations needs as well as the present generation. Farming practices need to be based on biologically sound ways of maintaining productivity. By incorporating the biophysical model DairyMod into the analysis, greater realism and detail is possible.

If we are to judge an activity to be sustainable, we need to consider both the private individual costs (and benefits) as well as society’s costs (and benefits). That is, total benefits and costs, private plus social, need to be considered. The economic and physical environments are not separate entities, particularly in the agricultural sector, where the activity is highly dependent on the environment and the state of the biosphere. When natural capital is combined with the other forms of capital, individual cost and benefits differ from those of society. An individual’s efforts to maximize utility does not necessarily equate with maximizing society’s utility, giving rise to the potential for conflict. It is important to make sure that all capital is valued correctly and by equating all the social costs with all of the social benefits, a sustainable outcome is possible. Combining a biophysical model with an economic model, as suggested in this paper, illustrates one way that can be used to incorporate social costs and benefits.

Sustainable agriculture, at farm, catchment or regional level, requires an understanding of the interrelationships between soil, plant and animal that determine the level if inputs required to ensure the maintenance of soil resources while also ensuring economic viability in terms of gross margins. Sustainable farming requires a balance between inputs and outputs over the long term. To be sustainable, farmers need to monitor not just their financial returns but also the health of their ecosystem – the soil, pastures and animals. A biophysical model, such as DairyMod, is one model that can be used at the individual farm level to determine ecosystem health.
The approach suggested here could be used to determine if farmers, or farms within a specific region, are operating in a socially efficient manner. The extent to which some natural resources are being degraded, for example soil and water, can be determined. If degradation is severe, policy could be adopted to reduce the negative impacts. Alternatively, the analysis could highlight that when the environment is fully accounted for, the farming practices are environmentally sound.

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