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Dairy Directions: A decade of whole farm analysis of dairy systems

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Abstract

Dairy farm systems are complex and diverse. Since the late 1990s, dairy farm businesses in Victoria, Australia have operated in particularly volatile natural, economic and policy circumstances, as well as dealing with the long-term challenge of persistently rising real costs and real prices fluctuating around a declining trend. Maintaining profitability in this environment requires sound decision making. Sound decision making in farming involves assembling, analysing and assimilating information about the whole system in a robust way. To assist this end, a decade ago, a dairy research and development project, Dairy Directions, was developed. In this program, the whole farm approach of farm management economics was used to investigate questions about options dairy farmers had to maintain and improve profitability, to achieve their goals. Commencing in one region of Victoria, with an initial focus on farm decisions, the scope of the work evolved to identifying gaps in scientific knowledge, contributing information to public policy formation, and expanded to other regions.

A steering committee of farmers, related industry representatives, scientists and farm economists proved the key to success in this research process. In this paper, the whole farm economics approach to farm systems research is described and explained; in particular the role of using information about response functions, risk, time and case studies in answering questions about alternative farm futures. The application and results of the whole farm approach to a range of research questions about dairy farming in Victoria is presented. As well as confirming the known, findings have also identified unrecognized dimensions, and challenged theory.

Key words: Farm management economics, risk, case study, dairy

1 Introduction

Dairy Directions is a research program about future dairy farming in Victoria and southern New South Wales, Australia. The program commenced a decade ago in northern Victoria. The initial aim was to investigate options for dairy farmers to maintain and improve profit in the face of persistently rising real costs and declining or flat real prices received. During this time, the complexity and difficulty of dairying increased as the natural, economic, finance, risk and policy environments became increasing volatile. The program evolved to cover broader questions, identifying gaps in scientific knowledge requiring research, and providing input to the development of drought and water policies. The initial research approach and program was replicated in other dairying regions of Victoria, and is being adopted in other industries. A timeline of the project is given in Appendix 1.

The rationale for this paper is that (i) the whole farm-production economics approach to analysing farm systems and to conducting farm systems research has long been established and documented, for example Barnard and Nix (1973), Bhoelje and Eidman (1984), Heady (1952, 1950, 1948), Malcolm *et al*. (2005), McConnell and Dillon (1997), but is often missing in analyses of farm systems (e.g. as reported by Malcolm 2004a); (ii) the application over 10 years of a distinctive research process in which whole-farm economic analyses of a range of research questions about dairy farming in Victoria warrants documenting and (iii) the findings and learning from applying farm management economics and farm systems theory to analyse choices faced by dairy farmers are interesting because some findings have confirmed theory; some findings have highlighted dimensions that were not obvious; and some findings have challenged theory.

The paper proceeds as follows: first the domain of dynamic farm systems research and the farm management economic approach is outlined, emphasising the role of information about response functions, risk, time and use of case studies to answer questions about alternative farm futures. The method and questions, and findings of the Dairy Directions project are elaborated. Conclusions are drawn. The key to this type of research is close connection between farmers, agricultural scientists, farm economists and people involved in both the pre and post-farm gate supply chain.

2 The domain of dynamic farming systems research

Dynamic farming systems research solves problems of operating farm systems over time by investigating components of the whole system, their responses and linkages, the effects of time, and the risks and uncertainties. In doing this, dynamic farm systems research builds understanding of the interactions, interdependencies and responses of farms, markets, natural environments and social systems over time and under changing conditions. Doing dynamic farming systems research involves imagining, analysing and contemplating alternative futures for farm systems and their operators.

Dillon (1976) said: 'the world does not come to us in disciplinary forms' (p.6) and further, '…science today increasingly tends to gain an understanding of the structure of the parts from an understanding of the functioning of the whole' (p.6). The central premise of problem-solving dynamic farming systems research is that solutions proposed to problems of the parts of a system are not necessarily solutions to problems of the whole system.

Attempts at understanding and explaining behaviour of farm systems – solving whole problems – without applying the whole farm approach are exercises in futility. Factors such as the motivations of the farming people, time as an input to production, risk, and the opportunity to change systems in response to changes around and within them can be usefully analysed using the core discipline of farm management economics (Malcolm, 2004a). The role of risk and uncertainty in farm management decisions and farm performance is central. Properly applied, the whole farm approach does all of these things, in the context of sustainability of the business and the natural resources, and in the light of farmer goals and their trade-offs through time. Some 'improper applications' of attempts at farm economic analyses in Australia are recorded in Malcolm (2004a).

At the same time, usefully employing a systems approach recognizes fully the potential follies of holism as noted by Leeper (1972) and Passioura (1973, 1996). That is, the folly of (i) thinking you cannot say anything about anything until you know everything about everything; and (ii) the shallowness, often evidenced, of understanding deeply about connections, but

insufficient about the parts that are being connected. Applied poorly, 'interdisciplinary' can mean 'no discipline'.

For dynamic farming systems research, knowledge required includes soil science, animal science, agronomy, engineering, agricultural economics, management, marketing, politics, sociology, and associated sub-disciplines. The appropriate level of system to look at, and the appropriate mixes of disciplinary and interdisciplinary knowledge to understand the parts and the whole, depends on the question at hand. To do useful dynamic farming systems research means doing the following steps:

- Identifying the question(s) and choices in real cases related to emerging challenge(s) or innovations that might improve productivity.
- Identifying the relevant planning horizon in which to consider problems and solutions, as well as the path of the production processes involved in moving from the *status quo* to the improved state.
- Identifying the interested parties (farmers, agribusiness, industry bodies, and government) and their issues.
- Understanding the interactions between the components of the whole system that determine performance.
- Incorporating views from various sources and perspectives.
- Identifying risks and uncertainties and their implications.
- Constructing whole farm models using farm economics as the core discipline, and validating them.
- Testing and evaluating predicted consequences of operational and management changes over time.
- Promoting the results to operators of farm systems in similar situations.

3 The whole farm/farm economic approach

3.1 Overview

Sometimes, there is talk of the whole farm approach to farm economics, as though there is some other approach. There is not. The core and integrating discipline of whole farm system analysis is farm management economics (Heady, 1952, 1950, 1948; Malcolm 2004a, b; McConnell and Dillon, 1997). The whole farm approach to research examines significant input-output relations and the interrelationships between component parts of the system that are important to the question(s) under scrutiny (Bachman, 1950). The challenge is to select aspects of the operation of the whole farm system, and study their contribution to problems farmers have in achieving their goals. The confounding challenge is that analysing particular questions about the farm system requires analysis of most other aspects of the farm business because of important interrelationships.

This process of whole farm analysis recognizes that each farm family is unique in terms of the resources they control, their history, stage of life, psychological make-up, attitude to risk, and goals. However, elements of the biophysical systems at work on farms, and important influences external to farms, are common. The problems, relationships and adjustment possibilities faced by managers of similar farms are not unique. However, the goals of farm managers, their preparedness and capabilities to learn about and implement new knowledge or technologies, and their willingness to bear risk, all differ.

Decision makers in the present are trying to achieve their goals with the resources they command, when much is unknown and uncertain. Approaches to research in farming systems that emphasise biological responses, farm economics, time, change and risk (i.e. dynamics) are essentially motivated by recognizing that one way or another the future will arrive. Assembling, analysing and assimilating information about the farm system, and thinking about choices, in a structured way has more chance of leading to desired outcomes than simply hoping to be fortunate. Farm decision-makers have no choice but to imagine alternative futures, master information, form judgements and choose between alternative possible futures that have varying likelihoods of success and reward. Whether this is done implicitly or explicitly, the choice is not between the *status quo* and an alternative future. In a dynamic world, the *status quo* is not an option. The virtue of imagining the future explicitly and in a structured way is that it lends itself to testing and rigour. Imagining possible futures with rigour is the key element of the Dairy Directions farm systems research program.

3.2 Response functions

The challenge with modelling the economic performance of whole farm systems is to go from knowledge about the key biological response functions that is at best of a general nature, to the amalgamated effects of these response functions which form the operation of the whole farm system.

3.2.1 Principle of diminishing marginal returns and maximizing profit

The fundamental principle of production is the principle of diminishing marginal returns of extra units of variable inputs added to the other inputs of a farm system (also known as the law of variable proportions). This principle means that as extra variable inputs are added to a production process with other inputs unchanged, beyond some initial level of input the extra production that is created diminishes with each extra input. The operation of the principle of diminishing marginal returns is so critical that processes of agricultural production and the behaviour of farmers cannot be understood properly unless the way this principle operates, and the implications for the technical and economic efficiency of the system, are well understood.

The initial units of an input that can be varied and added to a fixed input, such as fertiliser (variable), added to land (fixed), or feed to cows, may initially have the effect of increasing quantity of output with each extra unit of variable input. This is called the increasing marginal returns stage of production. In this stage, the added variable input is raising the average production from all of this variable input. Beyond the stage of increasing marginal returns is diminishing marginal returns. As more variable input is added, the extra production that results diminishes with each extra unit of input. Total production continues to increase, but at a slowing rate. Total production continues to rise until it reaches a maximum. This stage, between where average product per unit of variable input is at a maximum, and where total product from all the variable input is at a maximum, is called the stage of diminishing marginal returns. Beyond this level, even if more inputs are added, output does not increase and can decline. This is called the stage of negative marginal returns. In this stage of variable input use, the same total production could be achieved using less input, so it makes no sense to operate in this stage of input use. Simply knowing that extra production will respond to extra variable inputs in the way outlined above tells farmers much about how much input to add to the other inputs in their production, and how much input not to use.

Theoretically, if responses to added variable input are known, and if sufficient working capital is available, the best level of variable inputs to use in an agricultural production process is where the value of the last extra unit of production brings in just a little more than the cost of the last unit of input. Thus the principle of diminishing marginal returns dictates that farmers wanting to maximise profit should strive to use a quantity of variable inputs:

- At least to the level where average product of the variable input is at a maximum (before this is too little input).
- Not beyond the level where marginal product from more variable inputs becomes negative (after this is too much input).
- In between maximum average product and negative marginal product is the ‘just right’ zone.
- Within the ‘just right’ zone of production, where the extra returns added from an extra unit of output just exceeds the extra cost of adding the extra unit of input.

In dairying, the theoretical decision rule about feeding cows to make as much profit as possible is to feed to where the extra return from another unit of feed just exceeds the extra cost of that unit of feed. The extra return is calculated as the quantity of extra milk fat and protein resulting from extra feed, multiplied by the price of fat and protein. The extra cost is cents per kilogram of extra feedstuff. This profit-maximizing rule from production economic theory about how much to feed dairy cows can be re-expressed as: if the marginal feed conversion efficiency of an extra unit of feed is known, feed at a level where the ratio of a kilogram of extra milk solid output divided by a kilogram of extra feed input (called the marginal product), is equal to the ratio of the cost of the extra kilogram of feed divided by the value of the extra kilogram of milk. This is the same as the economic criterion of ‘feed to the level where the marginal return just equals the marginal cost of feed’.

As it happens, the ratio of extra output to extra feed input is also a measure of the marginal feed conversion efficiency (FCE) of a marginal unit of feed. So, the theoretical profit-maximizing rule for feeding cows becomes: feed the cows to the level where the FCE of the last unit of feed fed equals the ratio calculated as the price of the last kilogram of extra feed supplied divided by the price of the last kilogram of extra milk produced. In practice the approach is (i) to be guided by this rule and (ii) make decisions that move marginal feed additions towards this position, while recognizing fully that this rule means other common feeding rules that are not based on production economic principles, such as maximizing average FCE over a time or maximizing average margin over average feed cost, will not produce maximum profit.

3.2.2 Moving along response functions versus moving onto new response functions

Analyses of farm systems often focus on using the variable and fixed farm inputs to make the most profit in a single short production period (e.g. a year). In the context of farmers achieving their major goals, tactical decisions about short term profit maximizing with the current system are often of lesser importance than the big question that farmers more often are asking – 'how to periodically move the farm system onto new production response functions to increase productivity under the changing circumstances and opportunities and declining terms of trade that prevail, and thus achieve the medium-term farm family goals?' That is, the major challenge for farmers is to be sufficiently flexible, in the business and mentally, to successfully adopt over time new technologies, systems and scales that move their farm system onto new, higher productivity production functions.

In practice, over any planning period, dairy farmers can be envisaged as adjusting inputs, especially the components of feed supply, to maintain and improve profit by (i) moving input use along current production response functions towards where marginal feed conversion efficiency = feed cost:milk price ratio, *and* (ii) changing elements of their feed system to establish new response functions, in pursuit of a higher feed conversion efficiency.

3.3 Risk and uncertainty in farm systems

Considering risk and uncertainty is central to conducting dynamic dairy farm systems research. Risk is about happenings with knowable odds. Uncertainty is about happenings with unknowable odds. It is possible to frame a market about risky happenings. Uncertainty refers to situations with virtually or totally unknowable odds: rare events not even considered as possibilities, or at best extremely rare possibilities in the tail of probability distributions. Uncertainties that matter are the rare events with unpredictable likelihood that have big impacts and consequences for farm businesses.

It is useful to distinguish between risks that relate to the operational side of running a farm business, called business risk, risks that relate to financing the business, called financial risk, and risks related to happenings in the marketing chain beyond the farm gate. The main sources of business risk are variability of weather, variability of prices after production decisions are implemented, and risks created by management having insufficient knowledge/skills to capture the benefits of innovations. Financial risk refers specifically to the amount of debt in a business relative to the equity (called gearing ratio). It includes fluctuating and uncertain cash flows available to meet constant commitments to interest, principle, and the consequences for rate of growth or decline in equity. Marketing chain risks include risks deriving from payment insecurity or inefficiencies in the system between producer and consumer. Whatever the level of business and marketing chain risk of a farming entrepreneur, financial risk deriving from the level of gearing exacerbates this level of risk. Further, risks categorized as being of a business, financial and marketing nature have tactical (short term) and strategic (long term) dimensions.

The trade-off between returns and risk is always to the fore because risk creates return. A low risk business is a low return business. For investors, higher returns are regarded as being more attractive than lower returns, and for choices with an equivalent return, generally more certainty is preferred to less certainty and less risk to more risk. The actions farmers take in the face of risks varies greatly depending on their make-up and goals, their particular situation, and the effects of time and the farm system they are running.

3.3.1 Managing risks and uncertainties in dairy farming

Managers cannot avoid making decisions about operating and changing farm systems. To do nothing different in a changing world is an implicit decision to take a chance on the current system performing satisfactorily despite the future circumstances changing. Managing farm risks and uncertainties involves taking steps that are both internal and external to the business. Dairy farmers manage risk and uncertainty by:

- Being technically good at farming – timeliness of operations, sound crop and animal husbandry.
- Growing the size of the business over time to increase output from their fixed resources to offset the effects of the cost price squeeze and remain cost-competitive with competitors.
- Conserving fodder during times of surplus to use in times of shortage.
- Strategically using water to get the most value out of irrigation.
- Having reserves of liquid farm and non-farm assets, and a reserve of borrowing capacity.
- Having high equity i.e. the business is not highly geared,.
- Keeping overheads low relative to output, gross income and total gross margin.
- Investing good year surpluses into good investments on and off the farm.
- Being well aware that intensifying farm businesses will increase the average net income and the variability of net income over time.
- Maintaining creditworthiness and having strong commercial relationships with input suppliers, including finance, and buyers of output.

Having flexibility to respond to short term and medium-term volatility of seasonal and market conditions by having capacity of fixed capital assets, saleable stock, reserves of liquid assets or fodder, or unused borrowing capacity available as needed, are key to coping with risk in farming. Retaining flexibility may mean lower income sometimes, but the business survives. In dairying, flexibility refers to the capacity to change elements of the system in response to changes affecting the system, such as shortfalls (surfeit) of expected water supplies or unanticipated increases (falls) in feed costs or falls (rises) in milk prices.

3.3.2 Analysing risky systems

Risk analysis of changes to systems is most informative when applied to sound technical representations of the business or parts of it, with a full understanding of how the business works and of the factors that determine success. Stochastic or risk budgeting involves attaching probabilities to different values of key variables, thereby generating a probability distribution of possible outcomes. This enables choices to be compared in terms of mean and variance of distributions of possible outcomes, e.g. using risk and probability tools that use Monte Carlo sampling from distributions of key variables and produce probability distributions of key criteria (profit, net present value, internal rate of return). Contribution to total variance of individual components of an activity or system can be identified using sensitivity analysis. This identifies the variables that are most critical to the performance of the activity or system.

Risk information can be presented as cumulative probability distributions and the stochastic dominance or uncertainty of alternative options identified, i.e. stochastic efficiency. Choosing an option on the basis of stochastic dominance presumes the decision maker prefers less risk to more if the same return was involved, i.e. risk averse. The advantage of the stochastic dominance approach in case study analysis is that (i) it does not require the decision-maker's utility function to be known and (ii) it is based on direct comparisons between probability distributions of outcomes. Stochastic dominance identifies sets of risk efficient operating conditions, but without considering the decision-maker's utility function. An additional refinement is to test the distribution of outcomes against discrete attitudes to risk – e.g. high aversion, medium aversion, low aversion – using the technique know as SERF (Subjective Estimation with Respect to a Function) (Hardaker *et al.,* 2004).

A version of sensitivity analysis is Break-even Analysis. For example, a critical variable would need to perform *at a particular level* for the change under consideration to be an improvement on what is currently done. Then, how probable is it that the critical variables will be at a level that achieves the required minimum return on marginal capital, and minimum net cash flow before interest and principle?

Combinations of events, or sequences of events over time, are also significant causes of incomes of dairy farmers fluctuating than the effects of variability of key variables alone. Analysing discrete scenarios enables the impacts of sequences and combinations of events to be considered. For instance, how would the whole farm balance sheet, profit, growth in wealth, net cash flow and debt servicing capacity look following a run of poor years for rainfall, irrigation water, feed costs and milk prices?

3.4 Time

The operation of a whole system is not an instantaneous event: it takes time. Time is an input to production decisions and an important part of analysing significant questions about farm systems. Change in farming is often about moving farm systems over a period of time onto new production functions to remain profitable, in response to changes in the economy, in nature and in technology. The relevant time over which to analyse the performance of a farm system depends on the question that is being asked. Decisions dairy farmers make can be categorized according to the time involved:

- Longer-term decisions about the direction of the business, such as land area, herd size, time of calving, type of feed systems on the farm, are generally termed strategic decisions.
- Medium-term or seasonal decisions, such as purchasing water or supplements to managing an emerging feed gap, are generally termed tactical decisions.
- Day-to-day decisions, such as which paddocks to graze next or to lock up for fodder conservation, are generally termed operational decisions.

3.5 Case Studies

The role of whole farm case studies in farm economics is well established (Crosthwaite *et al*., 1997; Malcolm, 2001). As all farm models only partially represent reality, case study farms simulated for economic analyses have a good chance of encapsulating the important features if they start life as an actual farm. Real case studies of 'what is' and particularly 'what could be' have been used in the decade of dairy farm analysis outlined in this paper.

Traditionally case studies of farm businesses were done by farm business management problem-solvers, and they were not regarded as a useful, or respectable, approach in agricultural economics and science research. The view was that, unlike the standard agricultural economics and science empiricism, designed to generalize from samples of populations to whole populations, it was considered that few general principles could be derived from individual case studies. But for some purposes, case studies of real and representative farm businesses, as they currently operate and as they could operate, provide information about real world phenomena that facilitates understanding them. Such understanding can be used to check against current theoretical understandings about how parts of the real world work. Thus, case study research is used to generalize to theory, and the analysis can inform other farmers running similar systems on their future options. The results of a real case study analysis are either consistent with theory, and add support to the explanations of current theory, or they are not consistent with theory and challenge accepted wisdoms.

The attributes and goals of farm families and the systems they run are unique. Emphasis on the uniqueness of farm businesses that justifies the use of case study approaches has a corollary: how can the findings about the state of affairs on one farm be useful and used to help farmers running other different farms? There are inherent differences in the feedbase systems implemented on farms in the temperate, Mediterranean and subtropical regions, and on rain fed or irrigated farms. However, emphasis on the uniqueness of farmers and farms clouds the extent to which there is also commonality between farms. Farms in a climatic region face generally similar weather, albeit with random occurrences, such as storms. Farmers producing similar products sell on similar markets and face similar input costs: the law of one price is a powerful phenomenon, where price differences in markets for products of the same quality and quantity sell for the same price after adjustment for differences in transport costs. The same biophysical principles, for example in pasture production or dairy cow nutrition, apply to all farms. In sum, different farms are subject to the same laws of nature affecting the internal workings of the farm business, and the same laws of economics and finance and effects of risk and uncertainty that operate in the external environment.

Some confusion about using results from case study research and development comes from the notion that an aim of extension is to say to farmers: 'You should do this'. The more useful approach is to say to a potential farm innovator: 'This is the information generated about future options from examining this case study farm; these are the methods used; this is the way to think about whether a change like the one in question is a good thing to do or not, and this is the way to use the information generated. If you want to test out the advantages and disadvantages of this innovation on paper, here is a set of farm budgets. Put your own numbers in them'.

4 The Dairy Directions project: an example of dynamic farming systems research

4.1 Overview

This 10-year research partnership between Dairy Australia, the Victorian Department of Primary Industries (DPI) and the University of Melbourne was initially known as the Future Dairy Farming Systems project, and more recently became Dairy Directions (Appendix 1). The broad brief was to answer key questions being asked about the future of different dairy farming systems in Victoria and southern New South Wales. To this end, an approach was developed to analyse farming systems that avoided the limitations of the static, partial, backward-looking, risk-less, accounting-focussed, economics-free approaches sometimes found in attempts at farm systems research (Malcolm, 2004a). The approach adopted in this project harnessed the strengths of the whole farm approach. It used case studies, emphasised farm management economics, and focussed on strategic management choices over a medium term, considering wealth, cash, profit and risk. Identifying the current and future challenges of dairy farmers is done by examining the choices that exist in real and representative dairy farm systems, and using the tools of farm management economic analysis.

The information that came out of the research was input into decision processes and management practices of a broader group of farmers. The work was multidisciplinary, and characterized by a strong emphasis on rigorous, robust biophysical and economic modelling of choices about alternative futures for representative dairy systems. It was informed by a range of scientific and economic disciplinary knowledge and practical farm management expertise.

4.2 Stakeholder steering committee

The first step was to establish the regional 'stakeholder steering committee' which comprised seven farmers, two consultants, a DPI extension officer, a DPI policy researcher, a rural counselling representative, a federal government environmental staffer, a water industry representative, the Director of the Australian Tropical Dairy Institute, a Dairy Australia program co-ordinator, and the project team. The project team comprised scientists and farm economists from the Victorian DPI and University of Melbourne. The roles of the steering committee were to define the questions, oversee the development of the approach, identify potential innovations (future systems), test the common sense of assumptions used in the modelling, provide information about the project as input to related work in extension and natural resource and dairy policy, and provide advocacy for the work when presenting it to farmer and industry audiences (Figure 1). In this way the group were involved every step along the way.

Around this core of expertise, many others contribute: people who can extend the messages; who deal with farm adjustment and finance; who supply key inputs (water, finance) or process outputs; whose focus is on natural resources of the wider catchment. Organising the appropriate mix of talent around the table is a necessary condition, but this is not sufficient for success. Success requires that the people around the table share common passion for farming, are intelligent and respect and like each other: ignorance and big-egos stifle discussion, destroy the essential camaraderie, and limit overall progress.

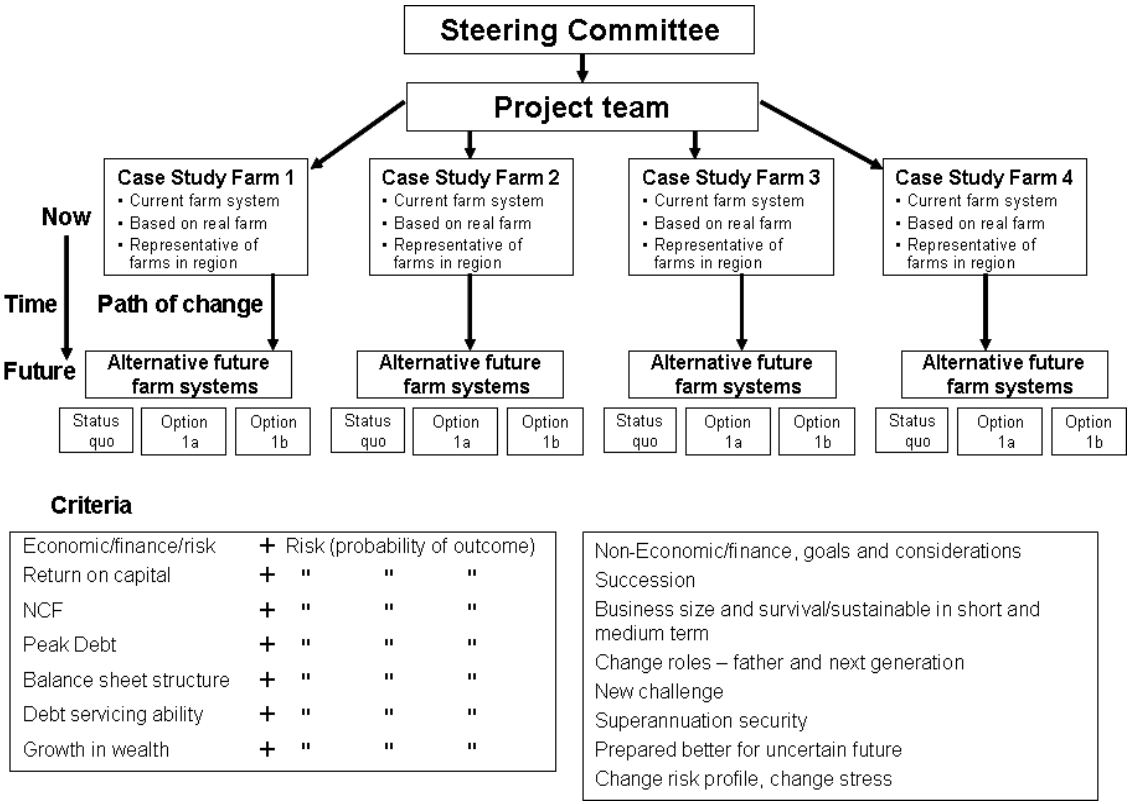

Figure 1. Approached used in the Dairy Directions project

4.3 The strategic questions

Business sustainability and growth, development options, and environmental effects, are long run questions. Short run or routine risk can be accommodated by traditional risk mitigation methods and cautiousness. The risks that matter happen over time. They also cause responses and changes to farm systems. To take account of important risks that occur over time, analyses have to be over multiple production periods, not single periods such as an annual steady state analysis. The main focus in this research was on the significant strategic questions farm businesses confront. 'Big strategic questions' involve the (i) time (ii) dynamics (iii) wealth and (iv) risk; questions such as:

- How to maintain profit or increase profit in the face of the long term rise in real costs and decline (or plateau) of real prices received?
- How to build the size of the business in the medium term to meet objectives of having sufficient wealth for later stages of the life of the owners, and sufficient scale of business for successors to farm profitably?
- How to operate the business with sufficient equity and debt to achieve growth in the good times *and* with sufficient equity to manage through, and even exploit opportunities in the bad times?
- How to incorporate new technology into the farm system to maintain and increase profit, considering risk?
- How to set up the farm system such that when all sources of risk and uncertainty are considered, the risk profile of the business is compatible with the risk bearing capacity and the objectives of the owners?

In building the budgets and models of the parts of farm systems and synthesizing these into whole farm models in order to answer strategic questions, the significant contributing parts of the whole farm system needed to be examined. The depth to which parts of the farm biophysical system were modelled depended on the question(s) being asked. The biophysical, economic and financial aspects of the operation of farm systems, and of development options, were modelled using computer spreadsheet budgets linked to tools of risk analysis. The performance of the base system for each farm type was analysed over 8 to 10 years under ranges of response functions (levels of technical efficiency) of the feeding system, and ranges in feed costs and milk prices. An annual real cost-price squeeze was included. This highlighted for farmers that the *status quo* is never an option in a dynamic world, and that continued improvement in productivity is necessary for profit levels to be maintained or improved.

4.4 Assessing the performance of the dairy systems studied

The case study farms chosen were well-managed businesses with ample, good information about inputs and outputs of the farm system. The farms were considered to be in the top 20% of management performance. Much was known about the soil nutrient status, irrigation practices, estimated feed production, and whether there were opportunities to further improve feed supply or improve milk protein and fat production per cow or per hectare. The farm managers identified development opportunities that had potential to deliver productivity gains to counteract declining terms of trade for each of these systems. Options for the farm being studied suggested by the steering committee were also examined.

The analysis of changes to farm systems and how they affect the performance of these systems were judged against criteria important to the farm owner. These criteria included both economic and financial aims, and non-pecuniary goals (Figure 1). The economic and financial performance of the farm system was assessed in terms of farmer goals of efficiency, liquidity, wealth and risk; concepts detailed respectively as annual steady state operating profit, annual return on capital and internal rate of return; annual steady state and cumulative net cash flow; net present value and growth in equity over the planning period, and climatic, yield, cost and price risk.

The budgeting was conducted from the starting point of the real case study farm being managed at a high standard. The method is to 'buy' the modelled farm business on day one of the future planning period and run the farm, in various ways under distributions of

conditions for key variables such as weather, prices and costs, over a relevant planning period, often up to 10 years, when the whole business is sold at a value excluding affects of non-farm changes in the value of capital assets. Real capital gains are recognized as a benefit, but separate from the farming activity. Resources that are generated internally, such as hay or silage or grain are either fed and valued as milk output, or bought and sold at market rates, depending on the question and the circumstances of the farm. The input-output mix of any farm plan (option) is tested for allocative optimality by using partial budgeting to 'creep' around the whole farm response surface (Cocks, 1964). Dairying is largely a single output activity (protein and fat) so the allocative optimality questions are about inputs of land, cows, feed, labour, water, machinery, infrastructure and debt.

In judging alternative changes for the farm system, the risk versus return characteristics of the development options analysed are always to the fore. To capture the risk dimension, the whole farm budgets and development budgets include probabilistic estimates for key risky variables, such as prices for protein and fat, purchased feed costs, availability of irrigation water and rainfall, and the variability of supply of home grown feed. The implicit assumption is that the essential form of the changed system being analysed (i.e. the input-output relations) will be maintained over a range of levels 'considered usual' for annual prices and costs of key variables. For circumstances outside this range, discrete scenarios are defined and explored. All options facing the representative farm business are compared and contrasted in terms of probability distributions revealing risk and reward trade-offs. Correlations between key risky variables were accounted for in the probability analysis.

The distributions of positive net present values of the investments in the farm at the end of the planning period for alternative ways of running the farm represent additions to wealth of the farmer above the wealth they would accumulate if their initial capital had instead been invested elsewhere and earned the opportunity cost rate of return (discount rate) for the duration of the farm planning period analysed. The farm development option that produces the highest net present value at the opportunity interest cost of capital, at a level of risk that is acceptable to the farmer, is the choice that is the most efficient use of capital and adds the most to the wealth of the farm owners, for their given view about acceptable risk. In farm management analysis, finance matters as much as economics. The distributions of patterns of cash flow and capacity to borrow also matter. Cash flows, ability to service debt, size of peak debt and rate of reduction of debt are critically important. The approach of investing in the farm, running it and then cashing it in, represents significant financial aspects of the business over time.

In summary, the Dairy Directions approach (as outlined in Figure 1) was characterized by:

- A stakeholder steering committee, deeply, keenly involved.
- The whole farm approach incorporating multiple goals, investment, time, dynamics, risk and the natural environment over a farm investment planning period.
- Modelling of a range of representative real case study dairy farm businesses and of the alternatives available to these farms in futures where there was a continuing cost-price squeeze; volatile milk prices; rising and fluctuating real costs of key inputs like feed, fertilizer and water; and highly variable rainfall and water allocations for irrigation.
- Detailed biophysical modelling of the major input-output responses of the farm system, incorporating diminishing marginal returns, as well as uncertainty about key relationships like feed conversion to milk.
- Risk analysis

4.5 Findings

Phase 1 (2001 – 2002)

(a) Evaluating alternate future options for four dairy farm systems in northern Victoria

Four dairy farm businesses, a 'traditional' family farm, a 'modified' family farm, a high input farm and a feedlot, were investigated as case studies. These systems were chosen as they represented different intensities of production, and different degrees of complexity.

The main findings from the analysis of the two pasture-based dairy businesses ('traditional' and 'modified' family farms) were that there were several feasible productivity-increasing options available that, done well, would enable these and similar businesses to combat the effects of the cost-price squeeze and maintain or increase profitability, wealth and financial viability (Ho *et al.,* 2005). Systems like these are exposed to highly variable export market prices, climatic conditions, and price or availability of a significant input, such as irrigation water, are not compatible with high levels of financial gearing which exacerbates whatever level of business risk exists. Success of these systems is based on producing efficiently home grown pasture or forage and adding purchased supplements and converting all feeds efficiently into milk protein and fat. These farms had opportunities to increase production through increased output per cow, but where pasture utilisation was already optimised, increases in production per cow or in herd size (stocking rate) could lead to reduced profit. This occurs as the extra milk solids produced effectively needs to be 'fully fed' with brought in supplements, which may happen at diminishing and low FCEs. Developing these low input systems into relatively higher input systems can increase costs, and risk, more than the commensurate increase in returns.

The high input dairy system and the feedlot dairy system had different constraints and imperatives. In these systems, the relationship between milk prices and feed costs and FCE is critical. A small change in this relationship had large effects, negative or positive, on the important economic, financial, net worth and risk measures of performance. Within these systems efficient production of home grown feed, optimising conversion of forage and concentrates into milk (effective ration formulation for high feed conversion efficiency) and the genetic merit of cows were key to success. Thus, these systems were not well suited to supplying milk for volatile export markets, nor to producing milk from feed supplies that are highly variable in nutritive characteristics or cost. The key to success of these high input systems is having some 'control' over the effects of market and environmental volatility. This is achieved through selling milk on domestic liquid markets where demand is stable, and short to medium term prices can be 'locked in'.

Phase 2 (2002 – 2005)

(a) Analysing the impacts of drought in northern Victoria and options for recovery, by adapting the dairy farming systems modelling approach

The serious drought of 2002/2003 reduced the water available for irrigation, and increased the price of water and supplementary feed for dairy farms in northern Victoria. Some of the case studies analysed in Phase 1 (above) were adapted to assess the impacts of drought on net cash flow under the vastly different, extremely difficult farming circumstances, of the drought (Armstrong *et al*., 2005). In all analyses, the drought and associated high feed costs caused deficits of net cash flow, as happened on most farms in the region. The options for dairy farm businesses to recover from the drought were also analysed.

This phase demonstrated how the Dairy Directions approach to farm systems research was highly responsive and adaptable because:

- The whole farm approach, and the balance of breadth and depth in disciplinary emphases was such that the analyses could be adapted quickly and efficiently to new questions.
- As reported in farmer workshops, and in several independent reviews, key information, and conclusions, about the representative case studies for each farming system was generally useful to most farms, without accounting for the detailed diversity present on individual farms.

- The project team and stakeholder steering committee had developed by this stage a strong understanding of the relationships between the key components of the farming systems under analysis and were able to readily adapt, assimilate new information, and understand thoroughly the implications of the changed circumstances of the business environment of the drought.
- The focus of the drought-related work was on helping farmers and their service providers ask the right questions about their businesses, and to discuss, learn, interpret and draw implications, rather than providing 'answers'.

The analyses of the drought and its implications for dairy businesses predicted net cash flow deficits that, on the majority of farms, would take several years to redeem. While these deficits and times to recovery would vary between farms, the analysis was valuable in informing farmers, business operators in the dairy service industry and various arms of government about the likely medium-term consequences of the drought, *during the drought*. Large dairy farms running high input systems were likely to have larger deficits of net cash flow than smaller farms running lower input systems. The analyses highlighted that the timing and quality of decision-making – recognizing the looming difficulties early and acting – was a key determinant of the ultimate impacts of the drought on net cash flows, irrespective of the farm system.

(b) Analysing the 40 year history of resource use, production, economic and financial performance, and productivity change, of an irrigated dairy farm in northern Victoria

This long-term case study was based on: (a) detailed records of milk production, herd, farm area and infrastructure, water and supplementary feed use, and estimates of labour use and pasture consumption (Melsen *et al*., 2006); and (b) financial information compiled from records of annual receipts and expenditures (Ho *et al*., 2006).

Total milk production from this farm business increased fifteen-fold over the 40 years. This came about through increased quantity and quality of inputs (cows, land, water, fertiliser, feed and labour) and increased output per unit of input (technical efficiency or productivity). Partial productivity measures, such as kg milk protein and fat per cow and estimated t DM pasture consumed/ha milking area, indicated that technical efficiency of inputs increased over time.

From the whole farm perspective, between 1980 and 2000, the business achieved gains in total factor productivity at a rate higher than the average rate of gain estimated for the whole industry (Ho *et al*., 2006). The productivity gains came from the timing and sequence of development on the farm, with investments in land and infrastructure occurring prior to the 1990s, followed by a period of intensification in which herd size was increased and more was supplementary feed used. The overall effect of expansion and intensification was to increase milk solids produced and dilute overhead costs (including opportunity cost of capital) per kilogram of milk protein and fat produced. An annual average of 3% real return on capital was maintained after these changes were made.

An important lesson from this study was that – despite common use - technical partial productivity measures are not indicators of economic well-being. A further major lesson was that declines in partial efficiency measures after development options are implemented, such as expansion of herd size and milking area, or the adoption of technologies, such as supplementary feeding, are compatible, and inevitable, with improved economic performance. This is consistent with the production economic theory outlined in section 3 which demonstrates that variable inputs should be used at least up to the level where average product (technical efficiency) of variable inputs applied to fixed inputs is at a maximum, and not used beyond the point where marginal product of variable inputs becomes negative. The most profitable level of output is somewhere beyond where average technical efficiency of added variable input is at a maximum and where marginal cost of extra variable input just exceeds marginal return.

Another significant finding was the critical importance of the time involved in developing newly acquired land to the level where it was producing similar amounts of feed as existing well-managed areas. *The time required to learn to manage the changed system, to develop the knowledge and skills to capture the benefits of new technology, the costs of operating the changed system, and the overall challenges of added complexity, are invariably all greater*

than anticipated during the planning stages of an investment. This delay in reaching and operating at full potential reduces the net benefits from the investment.

Phase 3 (2005 – 2009)

As the value of this approach became evident in northern Victoria, interest from other regions led to the approach being extended to Gippsland and south-west Victoria in Phase 3.

(a) Evaluating alternate futures for a dairy farm in Gippsland, Victoria.

The case study farm in the high rainfall region of Gippsland was a farm business milking 350-380 dairy cows on 140 ha of milking area and 105 ha of non-milking area. Three possible changes to the system were suggested by the Gippsland steering committee for this case study farm, including milking more cows on the same land area, purchasing more milking area, and purchasing an additional outblock (Armstrong *et al*., 2010; Tarrant *et al*., 2010). A number of options were considered for each of these changes. For example, when additional milking area was purchased, the stocking rates analysed ranged from 2 cows/ha (more land with the same number of cows) to 3.5 cows/ha (more land plus intensification). Expanding the milking area without significantly increasing herd size had the most attractive risk-return outcome. This choice achieved the rare, but highly desirable double of increasing average annual profits and reducing variability of these profits. Optimising use of the home grown feed (particularly grazed feed) and using purchased supplements efficiently was critical, particularly when the milk produced was subject to fluctuating prices on the export market.

(b) Viability of irrigated dairy farms in northern Victoria with changing water availability.

During Phase 2, the impacts on the viability of two dairy farm types of changes in water policy affecting water availability and costs were evaluated to inform discussion of the Victoria Government's Green and White papers (Department of Sustainability and Environment, 2004). This analysis was conducted by varying water allocations and/or prices when the farms were operating in a steady state (Ho *et al*., 2005). Importantly, the considerable scope that always exists to substitute inputs of fodder and concentrates for irrigation water was identified and quantified, for a wide range of policies for water supply (Ho *et al*., 2007).

In Phase 3, four water availability scenarios were imposed on the medium-term biophysical and economic performance of two case study farms in northern Victoria (Ho, 2010). The scenarios represented: (a) long-term average availability based on the historic records from 1891, (b) conditions under medium climate change based on CSIRO modelling; (c) conditions based on a continuation of the 10 years of low inflows experienced between 1997/98 and 2006/07 and (d) an extended run of years where water allocations were low.

Both case study farms had systems based on grazed pasture, with grain supplements fed in the dairy and conserved fodder fed in the paddock, but differed in the resources available, herd size and feed production systems. The economic performance of the farms was initially examined under each scenario without changes to the initial feeding system, while maintaining per cow production. Strategies to manage the impact of changes in water availability were tested, namely increasing milk production per cow by feeding more supplementary feed without changing the feeding system; changing the feeding system to present supplements in a partial mixed ration; and increasing milk production with a partial mixed ration feeding system. Feeding supplements as a well formulated mixed ration should help convert nutrients to milk protein and fat by reducing negative associative effects between feeds (i.e. because of more efficient rumen fermentation) and, by reducing waste of conserved fodder as compared with feeding grain in the dairy.

Unless the farm system was changed neither of these two case study farms were profitable under a medium climate change scenario, or a scenario where there was a continuation of the low inflows of water into irrigation systems experienced between 1997/98 and 2006/07.

The interesting finding was that under the medium climate change conditions, implementing an efficient partial mixed ration system and increasing per cow production enabled the larger farm to maintain and increase average profit. However, risk, assessed as variability in annual profit, increased compared to a feeding system where supplementary grain was fed in the dairy. More severe decreases in water availability meant neither farm was profitable when supplying milk for export, even with more efficient feeding systems. More significant changes to the farm system other than feeding additional supplementary feed to increase milk

production and/or using a partial mixed ration system would be needed for these types of farms.

(c) Evaluating alternate futures for a dairy farm in south-west Victoria

A farm with 570 milking cows on 233 ha of milking area (2.4 cows/ha), plus 338 ha of non-milking leased area was used as a case study in south-west Victoria. Five alternate futures were defined and described for the business. Analysis of these alternate options aimed to investigate the economic feasibility, financial implications and relative riskiness of particular changes on the business. Alternative futures for the case study farms included:

i. Increasing the amount of pasture consumed (t DM/ha) on both the milking and non-milking land.
ii. Increasing the milking area (effectively decreasing stocking rate to 1.9 cows/ha) with a concurrent increase in pasture consumption on the milking and non-milking areas.
iii. Increasing the milking area and increasing herd size (800 cows, 1.9 cows/ha) with concurrent increase in pasture consumption on both the milking and non-milking areas.
iv. Having no non-milking leased land and reducing herd size to 370 cows (with a concurrent increase in pasture consumption on the milking area).
v. A herd of 570 cows, no non-milking leased area (with a concurrent increase in pasture consumption on the milking area).

Results from the analysis endorsed the truth of the farmer adage 'if you are standing still you are going backwards'. The alternate futures that were investigated involved both intensifying and extensifying, and both choices worked in the sense that performance measured by a range of indicators of returns and risk promised to improve markedly over the performance of the system under a *status quo* future (Heard *et al*., 2011, Leddin *et al*., 2011). Further, this approach of investigating questions dairy farm owners and managers were actually asking was able to provide transparent and relevant information to other farmers in similar situations, managing similar economic and natural phenomena within and beyond their farms. Interestingly the two most attractive options in terms of risk and return were increasing the business size to milking 800 cows or reducing the size of the business to milking 370 cows. As theory would predict, the more larger, more intensive system promised greater wealth achieved by taking on more risk.

4.6 Confirming and challenging accepted principles

The Dairy Directions project has produced findings that confirm farm systems/farm economic theory, findings that highlight extra dimensions that are not always obvious, and findings that challenge theory.

Some of the findings that confirm the theory (or generally accepted principles as set out in Heady, 1952, McConnell and Dillon, 1997, Malcolm *et al.,* 2005) are:

- Doing nothing different in the face of a 1% per annum cost price squeeze guarantees a farm family's real wealth will be less in the future than current levels.
- The effects of volatility of milk price on farm performance measures generally swamp other sources of volatility, such as grain and water price fluctuations.
- Diminishing marginal returns from extra feed and negative associative effects between feeds when estimating metabolisable energy supply in dairy farm simulations have significant effects on outcomes. If these two phenomena are not included, results will in many instances overestimate business performance. When increasing the proportion of grain fed in the cow diet, allowing for a reduction in feed conversion efficiency of the whole feed ration gives results that are more realistic than happens when such effects are ignored.
- The capacity to substitute fodder and/or grain for irrigation water ameliorates, to a considerable extent, the adverse consequences of reduced availability of supply of irrigation water. However, this changes the risk profile of the business.
- Increasing grain feeding increases exposure to grain price volatility and increases volatility of whole farm performance compared with less grain fed in the ration.

- The most profitable options for a farm do not align with increases in particular measures of partial productivity, such as technical efficiency ratios of stocking rate per hectare, annual average FCE, kg protein and fat/cow or per hectare, water use efficiency, dry matter consumption per head, gross margin per megalitre of water and so on. Such technical efficiency/partial productivity measures, or average measures, give no guide to the best changes to make to the whole-farm system to achieve goals to do with profit, cash, wealth and risk. Maximum profit can be consistent with a wide range of technical efficiency ratios, depending on the costs of inputs and the prices of outputs.
- Internal biophysical response relationships, such as pasture production in response to fertiliser and irrigation practices or the feed conversion efficiency achieved using particular feeding systems are relevant to other farms engaged in similar forms of production.
- The effect of reducing average total costs of output by increasing output from fixed resources.

Some findings that illustrate dimensions of innovations that often have technical or science appeal, only to be shown otherwise by farm economic analysis are:

- The time it takes to fully implement and have fully operational a change to a farm system is a critical determinant of the success or otherwise of the change. Generally, it is several years before a change to a farm system is operating at the levels that are planned for and are necessary to justify the change (i.e. substantial opportunity cost).
- The replacement of irrigated perennial pasture with annual pastures using a mix of rainfall and strategic irrigation watering is a sound option, particularly for farms with few high security water shares and little annual pasture. The greater flexibility of the annual system enables farmers to better match their feed systems to more variable water systems. For other farms, replacing some irrigated annual pasture with irrigated perennial pasture can be a sound option.
- To be consistently profitable, meeting cash, wealth and risk imperatives, high input, year round systems such as total mixed ration systems, are best suited to selling on the domestic milk market at prices that are higher and less variable within a year than those received by producers supplying export markets. The relations between feed costs, milk prices and consistent high output are the keys to profits in highly intensive systems, with small changes in feed costs having large effects, for good or bad, on business performance.
- The positive impacts on profitability of many dairy systems from investing in high technology, capital-intensive irrigation systems like sub-surface irrigation and centre pivots which can increase technical water use efficiency, can be small relative to other changes that could be made in systems. At least in the northern Victorian irrigation region, these technologies are not generally options that will overcome problems of small farm size or adverse effects of the cost-price squeeze and income volatility.
- There are as many systems as there are farmers. In the right hands, provided fundamental requirements of size and high quality management are met, many different systems can succeed, i.e. it is not what you do as a farmer, but how you do it.
- Being technically very good is a necessary, but not sufficient condition for dairy farming success: business size and gearing (the principle of increasing financial risk) matter a great deal and, ultimately, are decisive.
- In some circumstances, extensifying (less cows, more land) can match or even improve farm risk/return performance more than intensifying (more cows, same or less land). This occurs in cases where the current stocking rate is above that needed to make best use of pasture consumption and a decrease in stocking rate can reduce reliance on purchased supplementary feed. This is also more likely when the farm has developed to the point where economies of size are limited.

- Economies of size (falling average total costs) beyond a medium size to large size are hard to find because the major components of costs in a dairy business are feed and labour and these increase quite directly with herd size.
- The lengthy time it takes to have a complex change in the farm strategy fully operational in the case study situation. This phenomenon will be found in other farms implementing complex change too.
- The scope for substitution of inputs in production on case study farms will have meaning for other farms with similar systems.
- The impact of the portfolio principle on activity mix and on whole business liquidity, efficiency and growth will apply similarly to many other businesses.

5 Conclusion

The Dairy Directions project developed from people in the dairy industry asking questions to which the answers could only be divined using the whole farm approach of farm management economics applied to the operation of dairy farm systems. In summary, the approach was a process that:

- Used consultation, engagement and well-established tools of farm management economics to collectively develop analyses to answer questions about dairy farm systems, while examining and illustrating the principles that apply to these systems. This enabled dairy farm decision-makers to answer similar questions and consider development options with data specific to their farm.
- Focussed on answering questions about parts and the whole of dairy farm system using whatever balance of depth and breadth of the range of disciplinary knowledge that was required.
- Asked questions common to dairy farmers running similar types of farms, even though the farms and farmers themselves are different. Taken as a whole, farm businesses are unique (largely due to operator goals, abilities to exploit the operating environment and skills), but they share common elements within the farm (soil types, feed production, livestock husbandry) and externally (market prices, exchange rates, costs) which enabled the deep analysis of one case study to be generalised into messages applicable to similar farm types.
- Focussed on representing dairy farm systems for the purposes of farm management investigation and problem solving and of learning - Dairy Directions is not ‘a model’ or ‘a decision support system’. Such are different, with different purposes.
- It is instructive to note that the research process that developed into Dairy Directions has consolidated over the decade it has existed and proved replicable from one region to three regions in Victoria. The research method is also being adapted to the lamb, cropping and horticulture industries in Victoria.
- For the Dairy Directions approach to work well a number of requirements had to be met, particularly involvement from a steering committee made up of:
- Intelligent knowledgeable and curious farmers.
- High calibre scientists whose depth of disciplinary expertise is accompanied by a sound appreciation for the farm as a system, i.e. old style agriculturalist as well as disciplinary specialist.
- Farm management economists who know economics and farming.
- Farm consultants who are very good at applying the whole farm approach; not just agricultural technologists whose focus is primarily technical efficiency and whose grasp of economic ways of thinking can be superficial and wrong.

Close involvement of farmers and discipline experts every step along the way were essential to define the problem, verify the numbers to use in the analysis or reality check assumptions where data was not available or knowledge was incomplete, and help to design the models and modelling approaches, and apply them. The advisory group of farmers and related-

industry representatives working with the scientists and economists proved to be the key to success of the Dairy Directions project.

The process of imagining alternative futures places the emphasis where it belongs, not on what was or what is but on what could be? Faced with change, risk and uncertainty, the problem-solving question is 'how might this farming system in the future best contribute to the goals of the farm family?' The future will arrive and it will be different; preparing for the challenges and opportunities of change remains the major and most rewarding imperative for managers of dairy farms and providers of dairy farm R, D & E services.

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Appendix 1. Timeline of the Dairy Directions project (2001 – 2009)