A Northern Tablelands Whole-Farm Linear Program for Economic Evaluation of New Technologies at the Farm-Level

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Table of Contents

Page

List of Tables

List of Figures

Acknowledgments

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Acronyms and Abbreviations Used in the Report

ABARE	Australian Bureau of Agricultural and Resource Economics
ABS	Australian Bureau of Statistics
AMLC	Australian Meat and Livestock Corporation (now MLA)
AWE	Australian Wool Exchange
BEEF CRC	Cooperative Research Centre for Cattle and Beef Quality
BU	Breeding unit
CDF	Cumulative Distribution Function
CFA	Cast-for-age
CPI	Consumer Price Index
DM	Dry Matter
DMI	Dry Matter Intake
DP	Dynamic Programming
DW	Dressed weight (or carcase weight)
HFS	Heavy feeder steers
K	the initial downward shift in aggregate supply due to technical change
LP	Linear Programming
LW	Liveweight
MAFF	Ministry of Agriculture, Fisheries and Food (United Kingdom)
ME	Metabolisable Energy
MIDAS	Model of an Integrated Dryland Agricultural System
MJ	Megajoules (of energy)
MLA	Meat and Livestock Australia
MOTAD	Minimisation Of Total Absolute Deviations (a mathematical programming method allowing a formal analysis of risk)
NFE	Net Feed Efficiency
NPV	Net Present Value
NTLP	Northern Tablelands Linear Program
NTMP	Northern Tablelands Multi-Period Linear Program
SCA	Standing Committee on Agriculture (Australia)
SHEEP CRC	Australian Sheep Industry Cooperative Research Centre
TGM	Total Gross Margin
TVC	Total Variable Costs

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Executive Summary

The benefits of evaluating a new technology in a whole-farm context using a linear programming framework are well known. Linear programming allows the joint evaluation of concurrent farm activities, while considering the costs and returns of all enterprises and any resource adjustments imposed by adoption of the technology. This Report provides a rationale for and description of a whole-farm linear programming model that can be used for the economic evaluation of new technologies that are applicable to beef/sheep grazing farms typical of the Northern Tablelands of New South Wales. In this farming system, the whole-farm focus incorporates various aspects of the pasture base, resource constraints and sheep and cattle interactions.

An overview of economic tools that are available to assess technologies at the farm level is provided first, listing some of the major benefits and limitations of each of these various techniques. A representative farm for the selected farming system is then developed and a whole-farm linear program based on this representative farm is described in some detail. A series of modelling experiments is undertaken to examine variations of the base model and their impact on the resulting technology evaluation. An example technology, involving the genetic improvement of beef cattle for improved feed efficiency (NFE), is evaluated.

The optimal farm plan for a "typical" (single) year is generated, given the objective of maximising farm total gross margin. Three enterprises are selected: 1,108 first-cross ewes, 1,732 Merino wethers and a beef herd of 127 cows producing 18 month old heavy feeder steers (HFS) at 448kg liveweight and excess heifers sold as 9 month old weaners. For this farm plan, the annual operating budget shows a total gross margin for the farm of $86,191.

The optimal farm plan for the representative farm is found to be sensitive to relatively small changes in input or output prices and production parameters. Only small improvements in a number of the individual enterprise gross margins would result in them displacing the currently selected enterprises. These results suggest relatively similar profitability levels between these sheep and beef enterprises. This would be anticipated given that all the enterprises described in this report were identified by local experts as being common in the Northern Tablelands. Further, the relatively small differences in enterprise profitability when viewed in a whole farm context also reflect the similar resources that each of the enterprises require, making them readily substitutable.

For new technologies that have dynamic attributes, measuring the cashflow over time becomes important. Genetic traits in ruminants that have long biological lags are such technologies. This means that a single-year equilibrium model will be unable to effectively measure the costs of introducing the new technology over time. In the case of the NFE technology in beef cattle, any herd expansion that is possible as a result of the trait is measured by the opportunity cost of heifer sales forgone that are instead retained to increase

the breeding herd. These herd dynamics can be represented explicitly within a multi-period version of a whole-farm LP model.

The NFE cow enterprise is offered to the model, with the initial sheep enterprises set the same as the base case (1,108 prime lamb producing ewes, 1,732 19-micron Merino wethers). The model again selects 127 HFS producing cows in the first year, but the new optimal farm plan is to invest in the new technology by purchasing NFE-superior bulls in successive years and expanding the cow herd while concurrently decreasing the scale of the Merino wether enterprise. Substitution of Merino wethers for NFE cows occurs up to year 12 after which additional breeding cows are possible from their increasing net feed efficiency alone. There is an increase in cow numbers of 12.6 per cent by year 25, which equates to an improvement in the NPV per breeding cow per year over the base herd of $5.02, using a 5 per cent discount rate. Other experiments reported include adding constraints for fixed costs, family drawings and an overdraft facility; alternate discount rates for the NPV calculations; alternate terminal values for the livestock assets at the end of the simulation period; and a post-optimality risk analysis.

This study has highlighted several additional benefits of evaluating a technology in a whole-farm multi-period linear programming framework. First, apart from determining the type and size of the optimal farm enterprise mix and the optimal value of the objective function, whole-farm multi-period linear programming also provides important additional information including shadow costs and prices and constraint slacks, and how they change over time. Shadow costs of activities show how sensitive the optimal farm enterprise mix is to changes in the gross margins of alternate farm activities not included in the current farm plan. The shadow prices for resources indicates how much a farm manager could pay for additional units of a limiting resource, for example, additional labour.

Second, in terms of the specific NFE technology examined in this report, it would appear that there may well be regions where such feed efficiencies may be of greater benefit due to particularly large variations in pasture growth patterns throughout the year. The Northern Tablelands with its recognised winter feed deficit may be one such area. This information may be of benefit to researchers in extending the NFE technology to farmers.

Third, the deterministic multi-period version of the model highlighted the impact of the inclusion of overhead and capital constraints in the modelling process in determining the potential adoption of a technology by a farm manager. The availability and cost of capital is shown to influence the extent to which the NFE technology may be adopted by an individual farm business.

Fourth, from a modelling perspective, the effect of uncertain terminal values and the bearing that they have on measuring the level of adoption of a new technology is an area for further investigation.

Finally, the impact of risk was assessed in this study post-optimally by the inclusion of stochastic output prices in the optimal whole farm budgets. This is an area for further research, including the potential of alternate modelling techniques such as MOTAD programming or stochastic dynamic programming. However due to size constraints, such approaches may necessitate trade-offs in terms of the detail of whole-farm models to which they are applied.

1. Introduction

This Report provides a rationale for and description of a whole-farm linear programming (LP) model that can be used for the economic evaluation of new technologies that are applicable to beef/sheep grazing farms typical of the Northern Tablelands of New South Wales.

Economic evaluations of new technologies are seen to be useful for government, producers and private research and development groups. The process of doing an e*x-ante* evaluation of a proposed research activity is often helpful in focussing the attention of the project proponents on the outcomes of the research and the possible limitations on adoption. In many instances the results of evaluation exercises contribute to the ranking of research proposals within the context of limited research funding and so lead to a more efficient use of these scarce resources. Similarly organisations with an interest in the extension of agricultural technologies, such as State Departments' of Agriculture and private consultants, need to identify the benefits of a new technology, including the economic benefits for farmers, to improve adoption rates of the technology amongst the target farmer group.

An overview of economic tools that are available to assess technologies at the farm level is provided including some of the major benefits and limitations of each of these various techniques. Of the major tools identified, linear programming has been found to provide an acceptable compromise between the incorporation of detailed biological, physical and financial parameters of the whole-farm system and the ease of finding optimal farm plans. A whole-farm linear program for the Northern Tablelands is detailed and a series of modelling experiments is undertaken to examine variations of the base model and their impact on the resulting technology evaluation. An example technology, involving the genetic improvement of beef cattle for improved feed efficiency, is examined.

2. Methods of Farm Level Evaluation of New Technologies

2.1 A Definition of "New" Technologies and their Evaluation at the Farm Level

A "new" agricultural technology is generally identified as a novel input or output to the farm system, such as new plant varieties, animal breeds, chemicals or equipment. However this definition can be broadened to mean a "different way of doing things" (Anderson and Hardaker, 1979, p. 12) and so have a greater application to more complex agricultural systems. Such a definition of a new technology would not only include new inputs or outputs but also the reorganisation of current practices, for example, changing the timing of farm activities within the production year, or changes in sowing and fertilizer rates or dates.

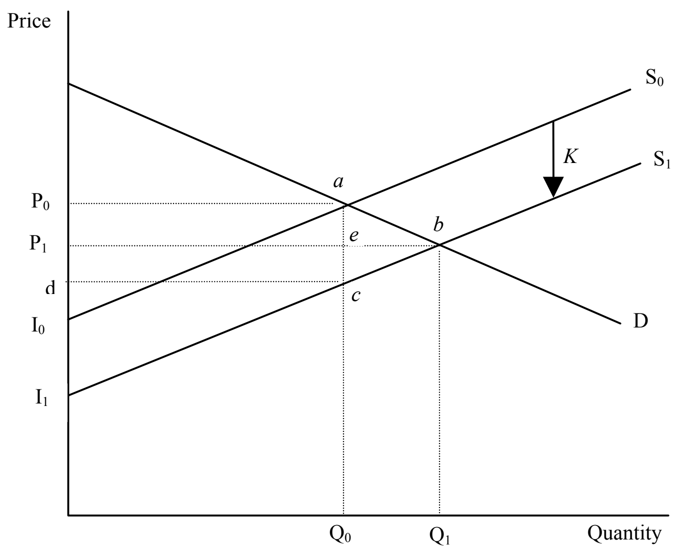
In general, the economic evaluation of new technologies as a result of agricultural research and development is based upon the notion of economic surplus. A new agricultural technology leads to an improvement in productivity in the industry and a consequent shift in the supply curve for the relevant commodity brought about by the adoption of the new technology by the target group. This shift in supply is known as the K-factor. The resulting economic surplus measure is disaggregated to determine the net benefit at the various market levels including producer surplus at the farm-level (Alston, Norton and Pardey, 1995).

At the farm-level, Alston, Norton and Pardey (1995, p.328) suggest that K is made up of two components:

- firstly, those changes in productivity that result when inputs are held constant to the level prior to the new technology; and
- secondly, the shift in supply that is a consequence of changes in the optimal input mix when the new technology is applied.

The relevant K is therefore that shift that results from the producer maximising their 'objective function', allowing the farm's input mix to be adjusted (Alston *et al.*, 1995).

Figure 1. A shift in the supply curve brought about by adoption of a new technology



In relation to Figure 1, this market is assumed to be in equilibrium at point *a* (P_0, Q_0). A new cost-saving technology reduces the cost of supplying the product by K, shifting the market supply curve from S_0 to S_1. After the market adjusts, a new equilibrium is found at point *b* (P_1, Q_1). The economic benefits of this new technology can be estimated as the area P_0abcd. Consumers benefit by area P_0abP_1, while producers benefit by area P_1bcd.

Thus the total economic benefit of the new technology depends on K. However, the information required to undertake a farm-level evaluation of a technology to estimate K, is not always immediately obvious. In discussing the evaluation of agricultural research, Pannell (1999) identifies categories of information that are applicable to the evaluation of technologies at the farm level. Any method utilised to undertake farm-level evaluations of new technologies should address as many of these information categories as possible. These include:

- the biological, technical and/or management changes from the new technology;
- the costs to the farm in implementing the new technology;
- the economic benefits accruing on a per hectare or per farm basis;
- the extent of adoption on the individual farm, for example, the number of hectares on the farm affected; and
- the impact of side effects from implementation of the new technology, which could be internal or external to the farm, including environmental impacts or price changes as a result of supply shifts of a farm output.

2.2 Methods

Several economic methodologies are frequently applied in the literature to undertake farm-level evaluation. Broadly these include budgeting techniques, linear and quadratic programming, dynamic programming and econometric approaches. Each of these broad methodologies differ in their data requirements and in the complexity of their development as well in their ability to measure the required components of the farm-level evaluation problem identified by Pannell (1999). A brief overview of the methodologies available for farm-level economic evaluation of technologies and a discussion of several strengths and limitations follows.

2.2.1 Technical Ratios and Partial Budgets

Two methods typically used as a means of initial assessment are technical efficiency ratios and partial budgets. They have limited information requirements and are simple to apply (Ghodake and Hardaker, 1981). In the case of technical efficiency ratios the new technology is compared with the traditional activity in terms of input-output ratios. Obviously such an analysis does not take into account economic efficiency and thus is of only limited use.

In the case of partial budgeting, the benefits of the technology under investigation are defined in monetary value terms and an attempt is made to identify those costs that will be incurred or affected directly from its implementation on the farm. This includes extra income and costs obtained by the farm and income and costs forgone from implementing the new technology (Makeham and Malcolm, 1993). The costs include related variable costs, and fixed costs such as the additional capital investment and depreciation necessary to utilise the technology. These budgets are typically set up on an annual basis. Tronsco (1985) identifies two significant limitations of the partial budgeting approach to evaluate technologies at the farm-level. Firstly, partial budgeting takes little account of the pervasive impacts of a new technology upon the whole-farm system and secondly, it cannot easily accommodate the impact of risk (although this is now less of a limitation with modern software packages). Further, where the benefits of the new technology accrue over time, discounting would be necessary to properly compare them with current costs.

2.2.2 Gross Margin Analysis and Budgeting

Gross margin analysis, cash flow and whole-farm budgeting are frequently applied for evaluating the economic benefits of new technologies at the farm level. These techniques have been reviewed by Dillon and Hardaker (1984), Makeham and Malcolm (1993), Farquharson (1991), and others. These budgets often form the basis for the more advanced mathematical programming methods. Budgeting methods are relatively straightforward to develop and the technical and price assumptions applied can be transparent. A further advantage of budgeting methods is that they are able to incorporate various degrees of sensitivity analysis to investigate the impact of uncertainty on the evaluation results.

A major limitation of these budgeting methods is that they cannot provide optimal farm plans so the issue of how and to what extent a farm manager is likely to adopt a new technology amongst existing farm activities remains undetermined.

2.2.3 Linear Programming

Linear programming is the most commonly applied method of optimising whole-farm plans from which to examine the benefits of a new technology within the whole farm context (Hardaker, Huirne and Anderson, 1997). As a whole-farm model, linear programming can examine the different farm activities within the context of various physical, financial and labour constraints. By optimising a specified objective function, linear programming can attempt to replicate how a farm manager decides to what extent a new technology is adopted on the farm. The objective function might be to maximise total farm gross margin or some other objective, for example to maximise total farm gross margin subject to a lifestyle constraint such as an upper limit on the use of family labour.

Apart from determining the type and size of the optimal farm enterprise mix and the optimal value of the objective function, whole-farm linear programming also provides important additional information including shadow costs and prices and constraint slacks (Pannell, 1997). Shadow costs of activities calculated by the linear program show how sensitive the optimal farm enterprise mix is to changes in the gross margins of alternative farm activities not included in the current farm plan. As well, the determination of shadow prices for resources indicates how much a farm manager could pay for additional units of a limiting resource, for example additional labour. Dent, Harrison and Woodford (1986) and Pannell (1997) provide extensive discussions on the use and interpretation of this additional information provided by linear programming models.

Typically the linear programming model is represented algebraically by the following:

$$\text{Maximise } z = c_1x_1 + c_2x_2 + ... + c_nx_n$$

Or

$$\text{maximise } z = \sum_{j=1}^{m} c_j x_j$$

where:

z = total gross margin of the farm,
x_j = the level of the jth activity (j =1,2,…,m), and
c_j = the gross margin of the jth activity.

This is subject to:

$$b_1 \geq a_{11}x_1 + a_{12}x_2 + ... + a_{1n}x_n$$
$$b_2 \geq a_{21}x_1 + a_{22}x_2 + ... + a_{2n}x_n$$
$$b_m \geq a_{m1}x_1 + a_{m2}x_2 + ... + a_{mn}x_n$$

or,

$$\sum_{j=1}^{m} a_{ij}x_j \leq b_i$$

where:
a_{ij} = amount of the ith resource required by the jth activity,
b_i = supply of the ith resource,
and, $x_1 \geq 0, x_2 \geq 0, \ldots, x_n \geq 0$; (Dent *et al*., 1986).

A further benefit of the whole-farm linear programming methodology in the economic evaluation of agricultural technologies at the farm-level is the ability to extend the model to incorporate risk. This development assumes that the incorporation of risk into the model and the farmer's attitude to it, will more accurately evaluate the extent of adoption of a new technology within a farm system. By doing so the model might more closely match the farmer's decision making priorities. However not all commentators agree with this view. Pannell, Malcolm and Kingwell (2000) suggest that "if the purpose of the farm model is to predict or evaluate change at the farm level, then the inclusion of risk aversion is often of secondary importance" (p. 75). They argue that it more important to get right the underlying physical and biological relationships than invest resources in more accurately representing risk in the model.

A variety of approaches to incorporating risk into linear programming have been developed including stochastic linear programming, quadratic risk programming, Minimisation Of Total Absolute Deviations (MOTAD) programming and variants of these. These methods have been reviewed over time by Anderson, Dillon and Hardaker (1977), Patten, Hardaker and Pannell (1988) and Hardaker, Huirne and Anderson (1997). Other methods have included the incorporation post-optimally, of a distribution of prices or production parameters for specific variables and a comparison of the before- and after-technology application of the resulting cumulative distribution of the objective function values (see Farquharson, 1991). Another extension of linear programming incorporates dynamic elements through the use of multi-period models (Dent *et al*., 1986).

Limitations of the linear programming methodology for the evaluation of new technologies at the farm-level include its relative complexity and the greater amount of information required to properly model the underlying biological processes, compared to the previously described techniques. Other limitations relate to some of the basic assumptions of linear programming: that inputs and outputs are divisible; that the relationship between variables is linear; that the combined effect of inputs and outputs is additive; and that inputs and outputs are constrained to be positive (Pannell, 1997). However, it can be argued that the limitations raised by these assumptions can largely be overcome through various modelling techniques such as those outlined by Pannell (1997). More generally however, LP approaches do not produce measures of welfare changes.

2.2.4 Dynamic Programming

Dynamic programming (DP) and optimal control theory potentially provide additional benefits in evaluating new technologies at the farm-level. Apart from the ability to examine the dynamics of a farming system and how a new technology might impact on the farm system over time, DP can incorporate non-linear biological relationships and stochastic attributes. Kennedy (1986) argues that while "linear programming is computationally much more efficient than dynamic programming for solving deterministic problems with a linear objective and linear constraints, dynamic programming may be more suitable for solving more intractable problems" (p. 6). A further appeal of the DP approach is that it provides a means of combining the modelling of complex biological systems, used by biologists, with stochastic variables and the optimality of resource-use principles (Trapp, 1989).

The DP approach is to separate the problem into a series of stages at which decisions are made, where the decisions made about variables that can be controlled at one stage have an effect on the outcomes (or states) in subsequent stages. The optimal solution is found by repeated solving of a recursive equation, or 'optimal value function' (Cacho, 1998). However a major limitation of this approach is the increasing complexity of the model and the associated data requirements. This in turn leads to the well established problem of dimensionality and the time that would be required to solve models with increasing numbers of variables. While this problem also exists for stochastic linear programming models, DP problems with a large number of variables (or state variables) reflecting the more complex agricultural system, quickly become impractical to solve in reasonable time (Cacho, 1998). However, alternative solution techniques to the recursive equation procedure used by dynamic programming, such as non-linear programming and genetic algorithms, can sometimes provide solutions in reasonable time (Hester, 1999; Cacho, 1998).

Cacho (1998) argues that a compromise can be reached between simplicity for optimisation and biological realism especially given that many of the variables that exist in a complex biological model have no impact upon decision making. That is, "the decision rules are not sensitive to the values of these variables" (p.13). This requires a process of carrying out sensitivity analysis of variables within a complex biological simulation model, combined with expert opinion, to identify variables which do not have a major consequence on the simulation results, to exclude these and hence to simplify the related bio-economic model.

2.2.5 Econometric Methods

An alternative method for evaluating the economic benefits of agricultural technologies is to apply an econometric approach (Alston *et al*., 1995). A measure of K needs to be provided as input, and measures of welfare changes are often produced as outputs. This methodological approach requires large amounts of cross-sectional or time-series data and generally takes the form of aggregate data across farms and regions. Further, assumptions about technical ratios embedded in the model may not be readily identifiable. The requirement for data generally excludes an econometric approach being applied to the examination of new technologies and those at the individual farm.

2.2.6 Summary

In summary the whole-farm LP method has been widely used to undertake economic evaluations of new technologies at the farm level. The LP approach allows for the incorporation of relatively complex whole-farm models while still maintaining the ability to find an optimal farm plan. Further, the general LP framework can be extended to incorporate various dynamic and stochastic attributes to suit the specific characteristics of the technology being assessed. The LP approach produces an estimate of K, which can then be used as an input into estimates of the welfare impacts of the adoption of new technologies.

In this report the Northern Tablelands Whole-Farm Linear Program (NTLP) is described and used to examine the potential farm-level benefits of specific agricultural research targeted at beef production. The model is based upon a representative farm. The whole-farm results presented in this report provide a picture of the profitability of the representative farm, for a particular suite of resources. As such they may differ significantly from any actual farm regarding differing resource endowments, climatic influences, management skills, market prices and costs and the farmer's goals and attitude to risk.

3. The Northern Tablelands Whole-Farm Linear Program

In this section a whole-farm linear program for a representative farm in the Northern Tablelands is presented. Following an initial overview, details of the various livestock enterprises, pasture, labour and supplementary feeding activities are provided. Further detail of the Northern Tablelands farming system, as well as a justification of the resources chosen for the representative farm, is provided in the companion Economic Research Report (Alford, Griffith and Davies, 2003).

3.1 Overview of the Northern Tablelands Linear Program

The Northern Tablelands Whole-Farm linear programming model (NTLP) is derived from the Department of Natural Resources and Environment's whole-farm linear program for various pastoral regions of Victoria (DNRE, 1999) as well as previous linear program models including Farquharson (1991). The NTLP is constructed to represent a typical beef-sheep farm on the Northern Tablelands of New South Wales. The choices of enterprise options to include were made in consultation with NSW Agriculture district extension and research staff and with several local graziers.

The model is deterministic and uses the same general approach as MIDAS (Kingwell, 1986) and other LP models[1]. The farming system is based upon a single year in equilibrium for which, in this case, various beef and sheep enterprises and management strategies are selected to maximise the farm's total gross margin. Calendar months are used as the time unit for farm activities. Following the method used to outline the MIDAS model (Kingwell, 1987), Table 1 shows the general structure of the NTLP matrix and the number (in brackets) refers to the number of activities and constraints allotted to various components of the LP.

The model is set up in Excel™ (Microsoft Corporation, 2002) spreadsheets and solved using the "add-on" software program What's Best™ (Lindo Systems 2001).

The grazing enterprises included are those that are common amongst Northern Tablelands graziers as identified through interviews with NSW Agriculture district extension officers and researchers and several district graziers. The management practices are based upon "best management practices" as described by NSW Agriculture officers. However management targets may be altered in the model, such as herd of flock reproductive performance, animal growth rates and pasture growth rates. Similarly, management strategies such as timing of calving or lambing can also be adjusted.

The basic NTLP matrix includes 166 activities and 112 constraints. Three sheep activities are available including a self-replacing Merino ewe flock, a Merino wether flock and an activity producing second-cross prime lambs. The beef enterprise options include a "local trade" vealer enterprise, a store weaner production enterprise, a young cattle enterprise (sold at 20 months, moderate growth), a heavy feeder steer production enterprise, and a backgrounding activity. These are described in some detail in Appendix A.

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[1] Although as MIDAS represents a mixed cropping-grazing system, the model optimises by choosing from a set of pre-defined rotations of related enterprises rather than from a set of individual enterprises.

Table 1. Outline of the structure of the Northern Tablelands linear program matrix

		ACTIVITIES										
CONSTRAINTS		Pasture types (3)	Choose Sheep enterprises (6)*	Choose Cattle enterprises (8)*	Casual Labour Requirement (12)	Pasture feed consumed or transferred (72)	Hay/Silage activities - make/ buy/sell (6)	Feed out fodder (24)	Buy/feed grain (12)	Sell animal products (23)	Sig n	RHS term
Land area (1)	ha	1									=	Area
Pasture type areas (3)	ha	1									<=	Area
Fodder constraints (4)	tDM or ha						1				<=	Area
Fodder pools Hay/grain (2)	MJ ME						-a, +a	+a			<=	0
Threshold enterprise levels (7)			1,-a	1,-a							<=	0
Pasture production (36)	MJ ME	-a				+a, -a					<=	0
Feed Pool (12)	MJ ME		+a	+a		-a		-a	-a		<=	0
Max. Dry Matter Intake (12)	tDM		+a	+a		-1		-1	-1		>=	0
Labour constraints (12)	Hrs		+a	+a	-1						<=	Max permanent labour
Animal Outputs (23)	Kg or Hd		-a	-a						1	=	0

Numbers in parentheses refer to numbers of rows or columns in matrix.
“a” and “1” refers to the coefficients in matrix.
Sign refers to type of constraint either equality or inequality in matrix.
* includes binary integers to incorporate minimum enterprise sizes (500 breeding units or wethers for sheep enterprises and 100 breeding cows for cattle enterprises).
Outline follows Kingwell (1987).

In the base NTLP matrix a large proportion of the activities and constraints are related to feed transfers between months and fodder conservation actions. The supplementary feeding of livestock also necessitates significant detailing.

To avoid the inclusion of impractically small enterprise sizes in the optimal farm plan, a series of threshold levels for the various animal enterprises are included. A minimum of 100 breeding cows is set for any beef activities and a minimum of 500 ewes or wethers is set for any sheep activities. These threshold activities are included in the LP by the use of binary integers, in a similar manner to that described by Dent *et al.* (1986).

3.2 Description of the Farm Activities

The pasture, animal, labour and feeding activities included in the NTLP are described below. The farm is assumed to have an area of 920 hectares, managed by an owner/operator with further part-time assistance from casual labour. Table 2 shows the LP matrix coefficients for the land and animal activities including minimum enterprise levels on a breeding unit (bu) or per wether basis, using binary integers as previously described, where the upper theoretical enterprise sizes are set at sufficiently high levels so as not to constrain the actual enterprise size determined by the LP. The associated sub-matrix detailing animal product outputs including wool (kg clean basis) and livestock sales (per head basis) is provided in Table 3.

The livestock production coefficients used in the NTLP are based upon management practices recommended by NSW Agriculture for the region. Quantities of wool are derived from analysis of the average clip quality and yields from Australian Wool Exchange data for the New England region and NSW Agriculture sheep budgets (Webster, 1998) and district extension staff. Animal liveweight, carcase yields and reproductive performance were obtained from NSW Agriculture beef (Llewellyn and Davies, 2001) and sheep budgets (Webster, 1998) and from estimation by NSW Agriculture district extension and research staff. The following discussion provides further detail of the pasture and livestock activities.

3.2.1 Pasture Activities Included in the Farm Model

As previously discussed pasture types including introduced perennial species, native pasture species and forage crops are utilised on Northern Tablelands farms. Assumptions regarding pasture types, establishment and maintenance practices and their performance were derived from a variety of sources including discussions with several district farmers, NSW Agriculture extension and research agronomists and from advisory publications, in particular Lowien, Duncan, Collett and McDonald (1997) and NSW Agriculture (1996). The representative farm with a total pasture area of 920 ha is assumed to have three major pasture types including native pasture 440 ha (48 per cent of total area), introduced species pasture 450 ha (49 per cent of total area) and 30 ha of forage oats (3 per cent). Thus, a typical area of forage oats is assumed, and the remainder of the area is split between native and introduced pastures based on ABARE survey proportions. Alford *et al*. (2003) provides a brief overview of the Northern Tablelands pasture base. The broad descriptions of the pasture types included in the Northern Tablelands model are:

Native Pasture – Native pastures including Red grass and Microlaena pastures with some clovers present based on soils of naturally moderate fertility. Maintenance fertilizer applications are applied at half the recommended rate. Assumed to occur on 440 ha or 48

Table 2. Land resources and livestock enterprises including minimum thresholds sub-matrix

		PPast	NPast	Oats	SRM	SRM500	PL	PL500	MW	MW500	VL	VL100	W	W100	YC	YC100	HFS	HFS100	sign	RHS
	Units	ha	ha	ha	bu	bu x500	bu	bu x500	hd	hd x500	bu	bu x100	bu	bu x100	bu	bu x100	bu	bu x100		
OBJ FN	$	-67.78	-25.40	-161.98	-22.48	-11239	-30.78	-15390	-19.24	-9620	-216.58	-21658	-65.57	-6557	-75.03	-7503	-81.51	-8151		
Land	ha	1	1	1															=	920
PPast	ha	1																	=	450
NPast	ha		1																=	440
Oats	ha			1															=	30
SRM bp	hd				1	-10000													≤	0
PL bp	hd						1	-10000											≤	0
MW bp	hd								1	-10000									≤	0
VL bp	hd										1	-1000							≤	0
W bp	hd												1	-1000					≤	0
YC bp	hd														1	-1000			≤	0
HFS bp	hd																1	-1000	≤	0

per cent of the model farm area (920 ha).

Introduced Pasture – Fescue/Phalaris grass dominated pastures with at least 20 per cent of base dry matter present as white or sub clover. These pastures are based upon soils of moderate to good fertility with annual applications of maintenance fertiliser. Assumed to cover 450 ha or 49 per cent of the total area.

Forage Oats – Sown in February on moderate to good fertility soils with recommended fertiliser rates. Oats is sown on 30 ha of the farm or 3 per cent of the farm area.

Pasture not consumed in one month can be transferred to the next month with an assumed loss of pasture dry matter of 10 per cent and a variable decrease in quality from 25 – 40 per cent depending on the month of the year. Pasture growth rates and quality assumptions are provided in Appendix B.

3.2.2 Sheep Activities Included as Options in the Farm Model

The Northern Tablelands growing season and locality influence the types of sheep and beef enterprises carried out. In the case of sheep activities, production potentially includes a wide variety of enterprises with Merino wool (particularly fine wool of 18-19 micron) dominating, but also with some prime lamb production. Super-fine wool production and first-cross ewe production are also carried out in the Northern Tablelands region. Sheep enterprises included in the NTLP include:

Self Replacing Merino Ewes – a self-replacing 19 micron ewe flock is joined to lamb in late August and September. Wether hoggets and excess ewe hoggets are sold at 18 months of age. Ewes are culled for age at $5^1/_2$ years of age.

Prime Lamb Production – First cross ewes (Merino x Border Leicester) are joined to a short wool terminal sire (eg., Poll Dorset) to produce second cross lambs for sale at approximately 6 months of age. Lambing occurs in late August to early October. Ewes are purchased at 18 months of age and joined to lamb at 2 years. Ewes are culled for age at $5^1/_2$ years of age.

Merino Wethers – 19 micron wethers are purchased as hoggets and culled for age at $5^1/_2$ years of age. In the model an average live weight for wethers is assumed to be 45 kg. They are assumed to be shorn in November.

Pre-lamb shearing of ewes on the Northern Tablelands is still generally practised within 4 to 8 weeks of lambing, while shearing of wethers may occur at other times of the year. For the purpose of the representative farm, shearing of ewes is assumed to occur prior to lambing and wethers are assumed to be shorn in October. Ewes have traditionally been shorn prior to lambing as a means of reducing casting in pregnant ewes and to improve lamb suckling (Miller, 1991) as well as to reduce the incidence of breaks in the middle of the fibre. An alternative view on the appropriate time to shear in summer rainfall dominant regions such as the Northern Tablelands is to shear in summer to reduce the incidence of fly strike and seed burden in the fleece (Bell, 1991; Marchant, *pers com*). However discussions with district extension personnel and farmers indicated that the late winter shearing of ewes remains the predominant practice in the region.

3.2.3 Beef Activities Included as Options in the Farm Model

British breed cattle predominate in Northern Tablelands beef production systems with some European breeds used for cross-breeding. Traditional enterprises have included breeding of store weaners for autumn weaner sales to local, north-western slopes, southern NSW, Queensland and Victorian producers who finish the stock (Llewellyn and Davies, 2001). Recently, the development of large feedlots in northern NSW and southern Queensland have provided the opportunity for Northern Tablelands producers to retain stock to grow to reach the feeder steer market. The local supermarket, European Union or grass-fed Japanese bullock markets have also expanded in importance (Llewellyn and Davies, 2001). Some specialisation by producers as 'backgrounders' of cattle for feedlots is also occurring in the region. Specific cattle enterprises included in the NTLP include:

Specialist local trade – occurring in the higher rainfall districts of the region where cows are joined to calve in July and early August to produce vealers at 9 months of age and 180 kg (d.w). These are heavier and better finished than weaners. Replacement cross-bred heifers are purchased in-calf.

Inland Weaners – cows are joined to calve in late July and August, and heifers are joined to calve at 2 years of age. Steers and heifers are sold at 9 months weighing approximately 240-250kg (l.w.) for growing and finishing in other regions or locally.

Young Cattle 15-20 months (moderate growth) – cows are joined to calve in August and September to produce yearlings, and heifers are joined to calve at 2 years of age. These are sold at 18 months of age weighing approximately 260 kg (d.w). Target markets for these cattle include the supermarket and wholesale trades.

Heavy Feeder Steers (Young Cattle 0-2 teeth) – cows are joined to calve in August and September, and heifers are joined to calve at 2 years of age. Heifers are sold as weaners at nine months of age, while steers are sold at approximately 18 months of age at 440-450 kg (l.w.) suitable for entry into feedlots.

3.2.4 Labour Activities

A labour constraint was included in the NTLP and was derived from labour requirements for various farm activities carried out on the Northern Tablelands estimated by Turvey (1988). These were subsequently reviewed by Farquharson (1991). In the NTLP these labour input values were adapted to monthly requirements in consultation with a cooperating farmer. Some adjustments were made to the beef cattle labour requirements to more closely match cattle turnoff dates and the timing of animal health procedures (Table 4). These labour requirements are of a simple additive nature on a breeding unit or per hectare basis and therefore do not account for any potential change in labour productivity as herd or flock size increases. This limitation of the data is addressed to some extent by the inclusion of minimum animal enterprise size thresholds.

A total of 250 hours per month of owner/manager and spouse labour were assumed to be available to the representative farm. This compares with an average of 264 hours per month

Table 3. Livestock commodity outputs sub-matrix (abbreviated)

		SRM	SRM500	PL	PL500	MW	MW500	VL	VL100	W	W100	YC	YC100	HFS	HFS100	Sell SRMW	Sell XBW	…	Sell Cowcfa	Sell Bullcfa	sign	RHS
	units	bu	bu x500	bu	bu x500	hd	hd x500	bu	bu x100	bu	bu x100	bu	bu x100	bu	bu x100	kg	kg	…	hd	hd	=	0
OBJ FN	$	-22.48	-11239	-30.78	-15390	-19.24	-9620	-216.58	-21658	-65.57	-6557	-75.03	-7503	-81.51	-8151	11.17	5.66	…	583.68	1197.00		
SRMW	hd	-4.56	-2282													1		…			=	0
XBW	hd			-2.94	-1472												1	…			=	0
MWW	hd					-3.00	-1500											…			=	0
PLL	hd			-1.06	-531													…			=	0
SRMEcfa	hd	-0.02	-11															…			=	0
XBEcfa	hd			-0.02	-116													…			=	0
MW	hd	-0.39	-194															…			=	0
MEw	hd	-0.12	-61															…			=	0
MWcfa	hd					-0.24	-119											…			=	0
RMcfa	hd	-.005	-2.5	-.005	-2.5													…			=	0
VLst	hd							-0.42	-41.6									…			=	0
VLhe	hd							-0.42	-41.6									…			=	0
WSt	hd									-0.41	-40.6							…			=	0
Whe	hd									-0.15	-15.4							…			=	0
WCull	hd									-0.04	-4.3							…			=	0
YCst	hd											-0.41	-40.5					…			=	0
YChe	hd											-0.14	-13.9					…			=	0
HFSst	hd													-0.41	-40.7			…			=	0
HFShe	hd													-0.18	-18.5			…			=	0
Cullhe	hd											-0.04	-3.8	-0.03	-2.9			…			=	0
VCowcfa	hd									-0.18	-17.7	-0.21	-21.0	-0.18	-18.0			…			=	0
Cowcfa	hd							-0.15	-15.1									…	1		=	0
Bullcfa	hd							-0.01	-0.9	-0.01	-1.0	-0.01	-1.0	-0.01	-1.0			…		1	=	0

of owner/manager and spouse labour used on Tablelands farms in 2000/01 year (ABARE, 2003). Apart from labour for livestock activities, labour allowances for pasture renovation and maintenance (as per gross margin budgets, see Alford *et al*. (2003)) are included in March for perennial pastures and native pastures and in December and February for forage oats. Labour requirements for these pasture activities were determined from NSW Agriculture farm budgets (NSW Agriculture, 2003).

Additional labour is made available in the NTLP through the casual labour activity for each month. An estimated hourly cost of this casual labour was set at $20.00 per hour. This was based upon the award rate for a casual station hand (Grade 3) of $14.33 plus on-costs and a travel allowance that would be payable (NSW Farmers, 2001). Estimates for the various labour requirements are detailed in Appendix A.

3.2.5 Feed Related Activities

Feed-related activities in the NTLP are based solely upon an energy demand model. This choice is a compromise between including more complex biological growth relationships and a more parsimonious model. In particular, the choice assumes that other necessary nutritional requirements such as protein, fibre, vitamins, minerals and water are not limiting to the ruminant. Typically for ruminants, grazing pasture energy and then protein are the primary limiting nutritional requirements, so ruminant simulation models such as Grazfeed (Freer, Moore and Donnelly, 1997), typically use energy alone or energy and protein requirements to derive feed requirements.

In the NTLP the feed required by the animal enterprises is expressed as metabolizable energy (ME) requirements (MAFF, 1984; SCA, 1990) on a monthly basis and matched with the ME provided by the pasture, including any carried over from the previous month and any supplementary feeding. As well, the maximum dry matter intakes of various livestock are accounted for. A summary of livestock enterprise ME requirements and maximum dry matter intakes on a monthly basis are provided in Table 5, while the equations for estimating ME and dry matter intakes for various classes of animals are provided in Appendix C. The assumed liveweights of the livestock classes by month are provided in Appendix A.

The pasture production for a ‘typical’ year in the Northern Tablelands in terms of dry matter production per hectare for the three pasture types previously described and the associated pasture quality (MJ ME per kg of pasture dry matter) were derived from NSW Agriculture (1996) estimates and from simulations using Grassgro (CSIRO, 2003). To overcome the complications of pasture-grazing animal interactions it is assumed that the maximum amount of pasture available to the grazing animals in the NTLP is half the amount of dry matter grown. In applying the model, this means that pasture harvested by animals in the lowest pasture growth month/s of the year will approach 50 per cent while in other months pasture utilised will be less than 50 per cent.

The model also allows for the opportunity of carry-over of pastures not consumed in any month. Table 6 provides a generalised representation of these feed transfers. The carry-over of pasture in terms of quantity (t DM/ha) and quality (MJ ME/kg DM) varies during the year depending upon a variety of factors including the phenology of the pasture species, climatic effects such as moisture and the occurrence of frosts, and animal effects such as trampling which is a function of stocking rate (Moore, Donnelly and Freer, 1997). In an attempt to

Table 4. Labour sub-matrix

		PPast	NPast	Oats	SRM	SRM500	PL	PL500	MW	MW500	Veal	Veal100	Wean	Wean100	YC	YC100	HFS	HFS100	CLbJan	…	CLbDec	sign	RHS
	Units	ha	ha	ha	bu	bu x500	bu	bu x500	hd	hd x500	bu	bu x100	bu	bu x100	bu	bu x100	bu	bu x100	Hrs	Hrs	Hrs		
OBJ FNC	$	-67.78	-161.98	-25.40	-22.48	-11239	-30.78	-15390	-19.24	-9620	-216.58	-21658	-65.57	-6557	-75.03	-7503	-81.51	-8151	-20.00	-20.00	-20.00		
LbJan	Hrs				0.037	18.5	0.033	16.5	0.028	14.0	0.20	20.0	0.2	20.0	0.20	20.0	0.45	45.0	-1			≤	250
LbFeb	Hrs			2.5	0.037	18.5	0.037	18.5	0.032	16.0	0.20	20.0	0.2	20.0	0.20	20.0	0.20	20.0		…		≤	250
LbMar	Hrs	0.092	0.014		0.062	31.0	0.058	29.0	0.053	26.5	0.65	65.0	0.52	52.0	0.40	40.0	0.65	65.0		…		≤	250
LbApr	Hrs	0.092			0.032	16.0	0.032	16.0	0.027	13.5	0.30	30.0	0.4	40.0	0.20	20.0	0.30	30.0		…		≤	250
LbMay	Hrs				0.027	13.5	0.027	13.5	0.022	11.0	0.25	25.0	0.28	28.0	0.20	20.0	0.25	25.0		…		≤	250
LbJun	Hrs				0.017	8.5	0.017	8.5	0.012	6.0	0.30	30.0	0.3	30.0	0.55	55.0	0.30	30.0		…		≤	250
LbJul	Hrs				0.017	8.5	0.017	8.5	0.012	6.0	0.30	30.0	0.3	30.0	0.34	34.0	0.30	30.0		…		≤	250
LbAug	Hrs				0.077	38.5	0.067	33.5	0.012	6.0	0.50	50.0	0.5	50.0	0.54	54.0	0.50	50.0		…		≤	250
LbSep	Hrs				0.042	21.0	0.042	21.0	0.012	6.0	0.30	30.0	0.3	30.0	0.42	42.0	0.30	30.0		…		≤	250
LbOct	Hrs				0.062	31.0	0.058	29.0	0.028	14.0	0.20	20.0	0.45	45.0	0.20	20.0	0.35	35.0		…		≤	250
LbNov	Hrs				0.077	38.5	0.073	36.5	0.083	41.5	0.20	20.0	0.2	20.0	0.20	20.0	0.20	20.0		…		≤	250
LbDec	Hrs				0.052	26.0	0.048	24.0	0.043	21.5	0.70	70.0	0.45	45.0	0.65	65.0	0.30	30.0			-1	≤	250

Table 5. Animal feed requirements and maximum dry matter intake

		SRM	PL	MW	Veal	Wean	YC	HFS
	units	bu	bu	hd	bu	bu	bu	bu
FPJan	MJME	658.7	769.9	259.8	4407.9	5057.3	6460.3	5638.7
FPFeb	MJME	618.6	771.7	224.3	4274.8	4812.4	5907.6	4897.3
FPMar	MJME	520.3	873.2	245.4	5596.4	5481.3	6030.5	4949.2
FPApr	MJME	493.0	477.5	241.2	4643.4	5522.3	5386.0	5083.1
FPMay	MJME	491.5	381.6	254.3	3380.0	4949.2	5127.3	4917.4
FPJun	MJME	428.8	270.8	247.5	3618.9	4082.1	4794.8	4364.8
FPJul	MJME	467.0	296.6	257.2	3947.4	4214.2	5233.1	4539.9
FPAug	MJME	545.0	364.9	260.6	3903.6	4379.5	5777.9	4769.4
FPSep	MJME	808.8	732.3	251.8	4019.6	4615.9	6067.3	5050.0
FPOct	MJME	820.5	737.2	263.7	4220.8	4951.3	6354.1	5348.8
FPNov	MJME	702.9	604.1	254.7	3952.3	4701.6	6003.4	5059.3
FPDec	MJME	652.6	681.9	262.8	4174.5	4746.7	6131.6	5188.5
DMIJan	t DM	0.087	0.084	0.039	0.588	0.605	0.741	0.679
DMIFeb	t DM	0.082	0.080	0.036	0.544	0.551	0.674	0.579
DMIMar	t DM	0.072	0.105	0.041	0.669	0.645	0.782	0.629
DMIApr	t DM	0.065	0.070	0.040	0.523	0.622	0.701	0.617
DMIMay	t DM	0.069	0.064	0.041	0.390	0.546	0.606	0.558
DMIJun	t DM	0.067	0.053	0.040	0.382	0.428	0.531	0.459
DMIJul	t DM	0.069	0.051	0.041	0.466	0.442	0.552	0.479
DMIAug	t DM	0.067	0.049	0.040	0.544	0.496	0.610	0.551
DMISep	t DM	0.073	0.057	0.039	0.542	0.557	0.662	0.617
DMIOct	t DM	0.081	0.066	0.040	0.569	0.598	0.704	0.655
DMINov	t DM	0.073	0.057	0.038	0.546	0.570	0.677	0.627
DMIDec	t DM	0.080	0.074	0.037	0.557	0.584	0.699	0.643

Table 6. A generalised representation of the feed transfer activities

		Perennial Pasture	Feed transfer to Livestock (month)	Feed Transfer from Prev. To Current Month (month)	Feed Transfer to Next (month)	Fodder cons. Hay (month)	Fodder cons. Silage (month)	sign	RHS
		/ha	t DM	t DM	t DM	/ha	/ha		
PPasture (month)	MJ ME	-a	+a	-a	+a	+a	+a	≤	0

'a' refers to coefficient in the matrix

address this complexity, pasture transfer activities are included in the LP based upon discounts for DM/ha and MJ ME/kg DM between calendar months that might be expected for a 'typical' year (refer to Appendix B).

The animal ME requirements (demand) and the supply of ME from pasture and supplementary feed sources are related by the use of a feed pool constraint for each calendar month. The quantity of pasture feed (MJ ME) from the perennial, native and forage oats pastures for that month plus the feed energy available from the hay and silage activities and the purchased grain are required to meet the value of energy required by the livestock enterprises for that month. Table 7 illustrates the general form of the feed pool constraint with the coefficient for the livestock enterprises taking a positive sign while the sources of feed (pasture, conserved fodder or grain) having negative signs. Additional sub-matrices for feed and pasture transfers activities and constraints are provided in Appendix D.

Table 7. A generalised representation of the feed pool constraint and associated activities

		Livestock enterprise	Perennial Past. Feed transfer to Livestock (month)	Native Past. Feed transfer to Livestock (month)	Oats Past. Feed transfer to Livestock (month)	Feed hay (month)	Feed silage (month)	Feed grain (month)	sign	RHS
		/ha	t DM	t DM	t DM	t DM	t DM	t DM		
Feed Pool (month)	MJ ME	+a	-a	-a	-a	-a	+a	+a	≤	0

'a' refers to coefficient in the matrix

3.2.6 Supplementary Feeding and Fodder Conservation Activities

Supplementary feeding and hay and silage activities and related constraints are detailed in the fodder conservation and grain supplementation sub-matrix (Table 8). Given the limited cropping activities carried out in the Northern Tablelands (refer to Alford *et al.,* 2003) there are generally limited grain handling and storage facilities. Therefore a constraint of a maximum amount of purchased grain for the representative year is nominally set at 10 tonnes on a dry matter basis (tDM).

In a similar manner, fodder conservation while often routinely carried out in the Northern Tablelands is in practice often opportunistic and constrained by factors not readily captured by a whole-farm LP model. For example, suitable topography and hazard-free land for machinery operation are often limiting in the Northern Tablelands for broad-scale hay or silage production while the risk of inappropriate drying/wilting conditions during the pasture growing seasons of spring and summer in the Northern Tablelands also increases the risk of their application. In the first instance, hay and silage operations are limited to a maximum of 5 ha on each of the perennial pasture and forage oats areas. Further, in the case of the perennial pasture, these activities are initially constrained to hay conservation over November and December and to silage production during October and November. In the case of the forage oats, hay production is limited to November and silage making is limited to October and November. There is also the opportunity to purchase hay, up to 20 tDM, in the representative year (calculations based on data in ABARE, 2003).

Table 8. Fodder conservation and grain supplementation sub-matrix

		PPast hay	PPast silage	Oats hay	Oats silage	Buy hay	Sell hay	Buy Jan grain	Buy Feb grain	…	Buy Dec grain	sign	RHS
	Units	ha	ha	ha	ha	t DM	t DM	t DM	t DM	t DM	t DM		
OBJ FNC	$	-65.98	-122.11	-50.08	-128.66	-164.71	110.00	-170.45	-170.45	-170.45	-170.45		
PP Consv	ha	1	1									≤	5
Oat Consv	ha			1	1							≤	5
Mgrain	t							1	1	…	1	≤	10
Mhay	t					1						≤	20

Additional sub-matrices that make up the NTLP are provided in the Appendices.

4. Implementing the Northern Tablelands Whole-Farm Linear Program

This section of the report provides an outline of an optimal farm plan for the representative farm for a representative year. Northern Tablelands grazing farms are very diversified and the mix of enterprises does not change markedly from year to year. Therefore, the discussion includes a method of determining commodity prices to use in the NTLP that reflects the long-term nature of sheep and beef cattle breeding enterprises. The commodity prices and costs used are discussed and the optimal farm plan for a representative year in 2001 dollar terms is presented. The resulting whole-farm model is then adapted and applied to a new technology in the following section.

4.1 Price Expectations and Commodity Prices Used in the Northern Tablelands Whole-Farm Model

Northern Tablelands grazing farms are typically diversified, including both sheep and cattle enterprises (refer to Alford *et al*. (2003)). One difficulty of a single-year, deterministic whole-farm model is that it does not capture the various capital and management constraints, including the farm manager's attitude to risk, that cause a farm to have a particular farm enterprise mix. In any actual year, particular commodity prices for sheep or beef cattle could result in one enterprise dominating other possible farm activities in terms of profitability. This problem of specialisation is further exaggerated where an LP model has not adequately captured important biological interactions that in practice limit the level of specialisation on a farm, for example, disease control with cropping rotations, resulting in optimal farm plans that are less diversified than seen in reality (Pannell *et al*., 2000). Parallels exist in grazing systems where complementarities between sheep and cattle grazing behaviours are used to manage pasture composition and control weeds, and where stock of different ages are used to control helminth burdens.

Sheep and cattle breeding enterprises require an extended period of time to introduce or expand as a consequence of biological lags, asset fixity and adjustment costs (Tomek and Robinson, 1990; Just, 1993). Producers may purchase breeding stock, however health and quality issues often limit such opportunities. Typically such enterprises are expanded by holding onto young females above the number required to simply maintain the current breeding flock or herd size. This limits the ability of producers to move into or out of a breeding enterprise in the short and medium terms. The biological lag that is represented by the time for breeding stock to be grown, bred and subsequently rear offspring to reach market specifications has been recognised in the cob-web theorem. Asset fixity reflects the difference in the cost of investing in an enterprise (asset) and the salvage value of those assets (Chavas, 1994). In the case of adjustment costs, these refer to the costs of adapting existing facilities or buying different types of livestock or equipment to alter production on the farm as well as the cost of information and knowledge required by the farm manager for different enterprises. This supply response lag has resulted in extensive research into how farmers form price expectations given that most agricultural commodity prices fluctuate significantly about a long-term price trend (Munro and Fisher, 1982). The existence of the cattle cycle is evidence of this phenomenon of farmers forming price expectations in the medium term and consequently expanding or contracting their herd size (Griffith and Alford, 2002).

A limitation of a single year linear program model is that it is assumed that factors of production are readily transferable between enterprises. Running the model using a single year's commodity prices may not reflect how farmers have invested in animal enterprises as a consequence of price expectations formed over a number of years. In an attempt to address this limitation, an assumption of how producers might form price expectations over the medium to long term is made by running the linear program using prices determined by following an adaptive expectations modelling approach (Judge, Griffiths, Hill, and Lee, 1980).

Various types of distributed lag models have been used to predict how a farmer might form price expectations of a commodity. Frequently, a geometrically declining lag has been used, which implies that an expected price is based upon a recent price and previous periods' prices with declining importance. This approach has not been accepted without criticism however. The theoretical bases of the underlying hypotheses of adaptive expectations and partial adjustment have been questioned, and in practice some prices may not be used by a farmer in forming price expectations, such as those prices caused by a major shock such as a crop failure (Just, 1993; Munro and Fisher, 1982). Another area of debate is to what extent price forecasts influence a farmer's expectation for the price of a commodity.

Two empirical studies of how Australian sheep farmers have formed price expectations (Munro and Fisher, 1982; Murray-Prior and Wright, 2001) have indicated that the long-term history of prices is an important factor in producers' production decisions. Northern Tablelands sheep producers in particular appeared to place little emphasis upon commodity price forecasts (Murray-Prior and Wright, 2001).

Murray-Prior and Wright (2001) suggest that rather than using the assumption of distributed lag models to determine price expectations, further research is required to investigate the modelling of price expectations and the possible inclusion of qualitative approaches in concert with econometric approaches may be more appropriate. Other aspects of modelling including the incorporation of risk and strategic planning adjustments within the linear program model would also potentially influence how commodity prices would influence the optimal enterprise mix (Hardaker, Huirne, and Anderson, 1997; Pannell, Malcolm and Kingwell, 2000).

However for the purposes of this study, the application of a geometrically declining distributed lag applied to relevant commodity price series was deemed suitable in the first instance. The impact of varying commodity prices on the optimal farm mix is investigated in the companion report (Alford *et al*., 2003). The weightings on the average annual prices, adjusted to 2001 dollar values by the CPI deflator, were based upon truncated geometrically declining lags, such that the index weights were 0.5, 0.25, 0.125, 0.0625, 0.03125, 0.015625 and 0.015625, for the years 2001 backwards to 1995, respectively.

Specifically, price series for beef and sheep sales were obtained from AMLC (AMLC, 1997) and MLA (MLA, various issues) statistics for NSW for the various classes of livestock product over the period 1995 to 2001. Similarly the wool prices used were the average annual clean price for the relevant microns (19 and 28 microns) from Wool International and Australian Wool Exchange over the period 1995/96 to 2001/02 (ABARE, 2003). Prices for replacement stock such as bulls, wether hoggets and first-cross ewes were obtained from NSW Agriculture beef and sheep budgets over the period 1995 to 2001 (NSW Agriculture, various issues *a,b*) and from sampling sale reports and classified advertisements from *The*

Land newspaper (Rural Press Group, various issues). All prices are expressed in 2001 dollar terms. The resulting average prices for the major farm outputs for the Northern Tablelands region are provided in Table 9, while Table 10 lists the major sources of input costs used in the representative year based upon 2001 costs.

Table 9. Commodity price assumptions used in deriving the representative year whole-farm budget

	Type	Price
Cattle Enterprises		
Vealers	steers	306 c/kg dw
	heifers	296 c/kg dw
Weaners	steers	167 c/kg lw
	heifers	157 c/kg lw
Young cattle	steers 20 m.o. 250 kg dwt.	283 c/kg dw
	heifers 18 m.o. 200 kg dwt.	273 c/kg dw
Heavy feeder steers (0-2 teeth)	steers 18 m.o. 450 kg lw.	170 c/kg lw
	heifers sold as weaners	157 c/kg lw
cfa stock	cows	256 c/kg dw
	bulls	266 c/kg dw
Sheep Enterprises		
Wool	19 micron wool	1 117 c/kg clean
	28 micron wool	566 c/kg clean
Merino	wether hoggets	$39.00/hd
	ewe hoggets	$42.33/hd
1st cross ewes	2nd cross lambs	100 c/kg lw ($48.00/hd)
Merino x Dorset	MxD lambs	85 c/kg lw ($31.50/hd)
cfa stock	ewes, wethers, rams	50 c/kg lw

Table 10. Sources of budget price data

Data Type	Source
Pasture input costs	Richardson's Hardware and Agriculture Pty Ltd, Armidale
	The Land Farm Costs Guide (Rural Press Group, 2001a)
Beef input costs	NSW Agriculture Beef Budgets (Llewellyn and Davies, 2001)
	Cooperating district graziers
Sheep input costs	Richardson's Hardware and Agriculture Pty Ltd, Armidale
	Cooperating district graziers
	The Land Farm Costs Guide (Rural Press Group 2001a)
	NSW Agriculture Sheep Budgets (Webster, 1998)
Livestock purchase prices	*The Land* sale reports for Northern Tablelands (Rural Press Group, various issues)
	District extension officers and cooperating district graziers

4.2 The Optimal Farm Plan

The optimal farm plan for the representative year was generated, given the objective of maximising farm total gross margin. Three enterprises were selected: 1,108 first-cross ewes, 1,732 Merino wethers and a beef herd of 127 cows producing 18-month old heavy feeder steers at 448kg liveweight and excess heifers sold as 9-month old weaners. For this farm plan, the representative year annual operating budget shows a total gross margin for the farm of $86,191. This farm plan required casual labour of $720 and fodder conservation and supplementary grain-feeding activities. No hay was bought. Details are provided in Table 11.

Table 11. Optimal farm plan for the Northern Tablelands representative farm

	Units	No.*	Gross margin ($) per unit	Farm GM
Farm Enterprises				
Prime Lamb Production	ewes	1 108	43.71	48,430
Merino wethers	wethers	1 732	19.65	34,034
Young Cattle (Heavy Feeder Steer production)	cows	127	419.26	53,246
Perennial pasture	ha	450	-$67.78	-$30,501
Annual pasture	ha	30	-$161.98	-$4,859
Native pasture	ha	480	-$25.40	-$11,176
Supplementary Feeding Activities				
Forage making (perennial pasture silage)	ha	5	-122.11	-611
Hay making (forage crop)	ha	5	-128.66	-643
Grain	tDM	10	-170.46	-1,705
Additional feed-out costs				-24
			Total Gross Margin	86,191
Casual Labour				
March	hr	36	-20.00	-720
			Total Gross Margin (incl cas. labour)	85,471

*rounded to nearest integer

4.3 Sensitivity of the Representative Farm Plan to Changes in Individual Enterprise Gross Margins

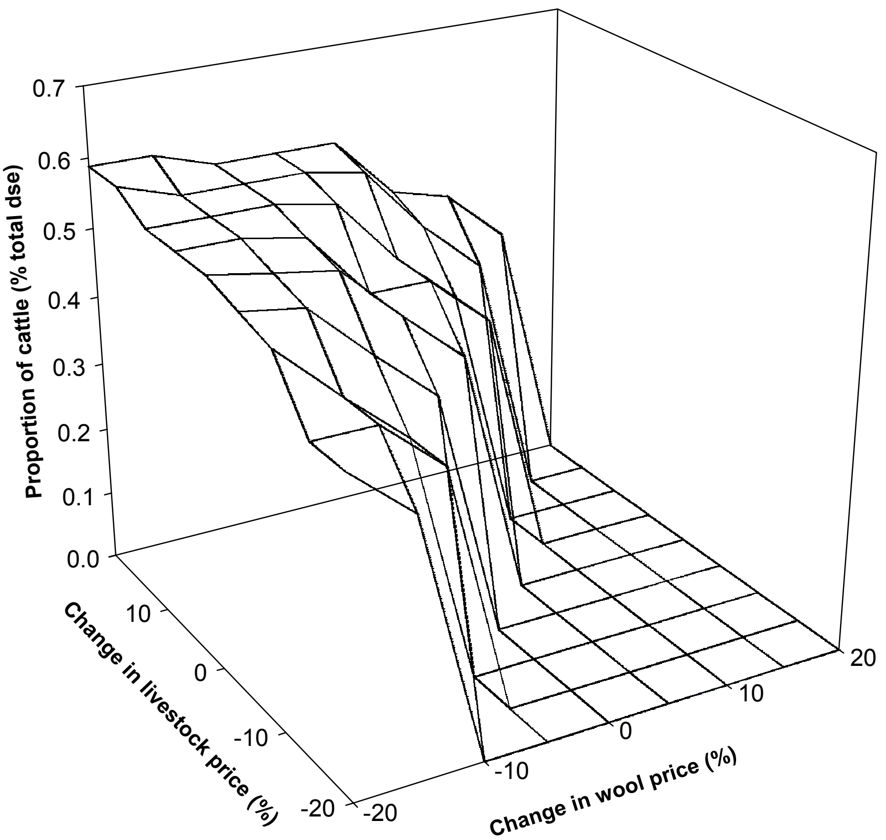
The optimal farm plan for the representative farm is found to be sensitive to relatively small changes in input or output prices and production parameters. For example, for the representative year, small improvements in a number of the individual enterprise gross margins would result in them displacing the currently selected enterprises. This is illustrated by using the model (Table 12) to determine the relative improvement in enterprise gross margins required for previously excluded activities to be selected into the representative year optimal farm plan, given the prescribed minimum enterprise size thresholds. With the exception of the beef weaner enterprise, the other livestock enterprise options require less than a 5 per cent improvement in the respective gross margins to be included in an optimal farm plan.

Table 12. Relative improvement in enterprise gross margins required to be selected in the optimal farm plan for the representative year

Enterprise	$ Improvement in GM per breeding unit	Per cent Improvement in Enterprise GM
Self Replacing Merinos	1.61	3.0
Specialist Local Trade	10.67	3.5
Weaners	60.31	19.3
Young Cattle (18-20 month)	18.30	4.1

Another way of illustrating this point is to graph the changes in the optimal enterprise mixes, over various livestock and wool price assumptions, in terms of the proportion of cattle DSE in total DSE for the representative farm (Figure 2). As shown, there are small changes in enterprise mix in response to small changes in relatively high livestock prices and relatively low wool prices, until a combination of relatively high wool prices induces a complete shift out of cattle.

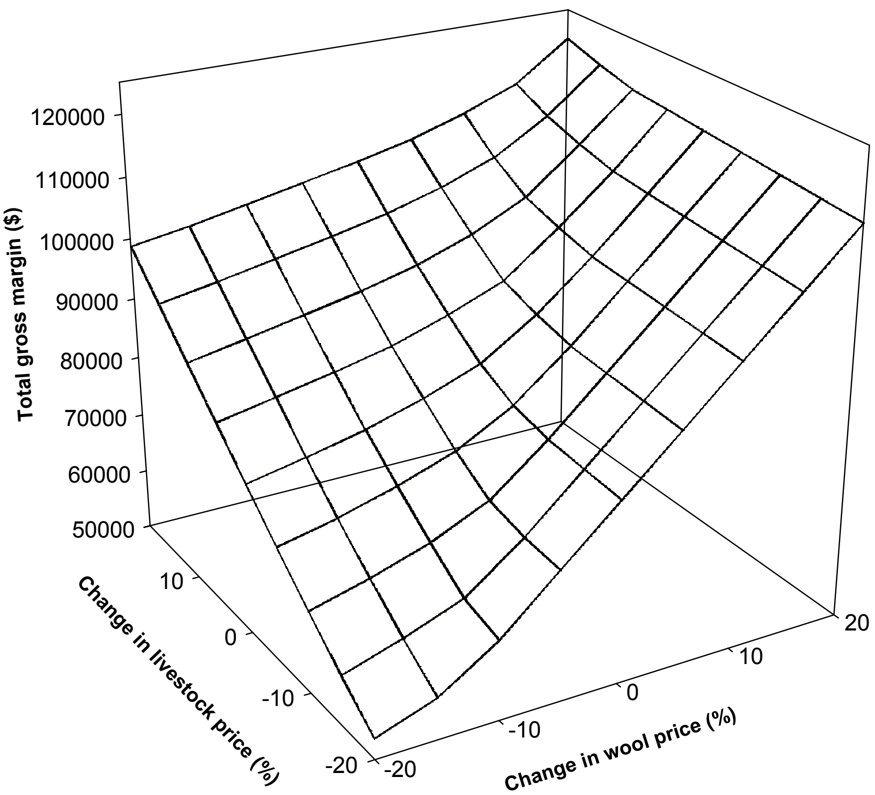
Figure 2. Change in the optimal livestock enterprise mixes in terms of the proportion of cattle of total DSE for the representative farm in 2001, over various livestock and wool price assumptions



These results suggest relatively similar profitability levels between these sheep and beef enterprises, over the range of sheep, wool and cattle prices used in the representative farm model. This would be anticipated given that the enterprises described in this report were all identified by local experts as being common in the Northern Tablelands. If one or two enterprises were significantly more profitable over a number of years then it would be anticipated that the majority of Northern Tablelands producers would have concentrated their farm investment in those specific enterprises. Further, the relatively small differences in enterprise profitability when viewed in a whole-farm context also reflect the similar resources used by each of the enterprises, making them readily substitutable.

These results imply that the profit response surface (Patton and Mullen 2001) (as measured by the total gross margin of the farm), would be fairly flat or unresponsive to variations in enterprise mix. This is shown in Figure 3.

Figure 3. Change in optimal total gross margin for the representative farm in 2001 over various livestock and wool price assumptions



The profit surface for the representative farm is relatively flat for given levels of wool price and for given levels of livestock prices, in spite of the changes in enterprise mix shown above. Further, the profit surface slopes smoothly and almost linearly down to the front corner of the graph as revenues from both wool and livestock decrease.

Given the relatively similar profitability levels of the various enterprises over the longer term, the likelihood of a relatively stable total farm gross margin, and the fact that the LP does not account for capital investment costs, the results do not support a strategy of frequently changing the enterprise mix in this farming system.

It should also be noted again that a limitation of the LP is that it is necessarily a simplification of the real world and does not capture all interactions that occur within the whole farm. A set of farm enterprises may be selected by an individual farmer to meet goals other than profitability alone, such as personal preference, labour requirements and management knowledge. As well, the model may not capture interactions such as the benefits arising from the complementary grazing effect of beef and sheep enterprises, or the preferences of graziers for breeding their own Merino wethers or replacement cows.

4.4 Validation and Verification of the Model

The testing of a model is recognised as an important aspect of any modelling process. Dent *et al.* (1986) outline two major components of model testing, verification and validation.

Verification refers to the consistency of the matrix with the problem to be addressed. For example, incorrect coefficients or constraint signs often lead to models that will not solve due to unboundedness or infeasibility. However Dent *et al.* (1986) argue that validation of a model is more subjective and in part is based upon whether the model outputs or solutions are realistic. Pannell (1997) outlines a framework for undertaking model testing.

With respect to the NTLP, the software used for solving the model, What's Best (Lindo Systems, 2001), will diagnose some verification type errors that might result in models that will not find optimal solutions. However Pannell (1997) notes that the checking of inputs and resolving any anomalies using various scenarios to ensure that the model results are consistent with *a priori* reasoning, is essential and takes time. The presentation of the NTLP matrix and associated herd dynamics, animal ME requirements and pasture coefficients in spreadsheet format assists in this verification and checking process.

In the case of validation of the model, a number of scenarios were tested using the NTLP including the technology scenario described in the following section of this report. In terms of broad validation, when the model was run using market-based prices for inputs and outputs and production coefficients were based upon published management expectations as previously described, the resulting whole-farm gross margin resulted in a realistic return on assets and equity as identified by ABARE farm surveys for the Northern Tablelands region (Riley *et al*., 2001).

Further, when the optimal farm plan was taken back to the local advisory and research staff who provided the input data, they all agreed that such an enterprise mix was broadly representative of the Northern Tablelands grazing system.

Two more specific validation tests were done. First, the stocking rate implied by the optimal farm plan was compared with that typically experienced in the Northern Tablelands region. The optimal farm plan determined by the NTLP described above is equivalent to 6.9 dry sheep equivalent (dse) per hectare. This is similar to the estimated carrying capacity ranges for Northern Tablelands pastures as identified by NSW Agriculture officers for "Fine Granite" type soils. These include a carrying capacity of 5-6 dse/ha (midpoint 5.5 dse/ha) for pastures which are fertilised and include some clover species, and 7.5-10 dse/ha (midpoint 8.75 dse/ha) for pastures that include introduced perennial grasses and clover and are regularly fertilised (Lowien *et al*., 1997). Given that the representative farm includes 480 ha of introduced pasture species (including forage oats), and 440 ha of native pastures, with some fertiliser and clover included, using the midpoints of these carrying capacity ranges would equate to an approximate carrying capacity for the whole farm of 6,620 dse or 7.2 dse/ha.

Second, the enterprise mix of the optimal farm plan can be compared with that drawn from 1996/97 ABS census data (ABS, 1998). In terms of percentages, the model under-predicts the size of the wool enterprise and over-predicts the size of the lamb enterprise, with the cattle enterprise almost exactly right. These differences reflect the problems mentioned previously of comparing the economic structure of the farming system in a particular year (the price of wool in 1996/97 was relatively low) versus that in a more "representative" year.

5. An Application of the Northern Tablelands Linear Program: Net Feed Efficiency in Australia's Southern Beef Cattle Production System

5.1 Introduction

In this section, the NTLP and associated whole-farm budgets are applied to estimate the likely economic benefits of improved net feed efficiency (NFE) in beef cattle[2]. This genetic trait has been a major research initiative of the Beef CRC. It has been extensively studied within British breeds of cattle and is therefore more likely to be applicable to Southern beef production systems (Exton, Herd, Davies, Archer and Arthur*,* 2000). The Northern Tablelands in New South Wales is one region where the technology may be particularly applicable.

Previous economic evaluations of the NFE technology (Exton *et al*., 2000; Archer and Barwick, 1999) have used gross margin and cash-flow budgetting techniques. While the use of cash flows has allowed the technology to be evaluated over time, these studies did not account for the technology within a whole-farm context. This analysis evaluates the NFE technology at the whole farm level using different versions of the whole-farm linear program described in the previous section.

The analysis proceeds by presenting a brief overview of the NFE technology. The NTLP is then extended into a multi-period linear programming (NTMP) model (Appendix F details the additional components of the NTMP). Two versions of the model are developed, the first maximises the net present value of total gross margins and the second maximises net worth after 25 years. The models are solved for the two cases, without the technology and with the new technology being available to the representative farm. Optimal results are then subject to post-optimality risk analysis with stochastic prices.

5.2 Net Feed Efficiency in Beef Cattle

Selection of beef cattle for increased feed efficiency is a relatively new research area. Feed-related costs represent the single largest cost category for a beef enterprise, typically greater than 60 per cent (Arthur, Archer and Herd, 2000). Previous selection objectives in beef cattle focused on the output side in terms of liveweight gain and fertility gains, as well as improved carcass traits (Archer, Richardson, Herd and Arthur, 1999). In contrast, selection for improved feed conversion efficiency is an attempt to reduce input costs. This approach has been especially successful within the monogastric poultry and pig industries.

NFE "refers to the variation in feed intake which remains after the requirements for maintenance and growth are accounted for. It is calculated as an individual animal's actual feed intake minus the expected feed intake based on its size and growth rate. Because an efficient animal is one which eats less feed compared to its weight and growth rate, efficient animals have a negative [NFE] while inefficient animals have a positive [NFE]" (Exton, Archer, Arthur and Herd, 2001, p.20).

[2] Another application of the NTLP model, evaluating the on-farm benefits of a potential new technology that increases the growth rates of pastures during the winter feed gap, is described in the companion Economics Research Report (Alford, Griffith and Davies, 2003).

Heritability of the NFE trait is moderate and of similar magnitude to the heritability of growth (Arthur *et al*., 2000). Archer, Arthur, Herd and Richardson (1998) estimated a heritability for the trait of 0.43. The physiological basis for feed-efficient cattle is uncertain, with various hypotheses proposed (Archer *et al.,* 1999). Further there is some uncertainty as to whether selection for efficient growing (young) cattle will result in greater feed efficiency for the overall breeding herd (Archer *et al.,* 1999). Major investigations have centred on feed efficiency of growing stock including the validation of a test to measure NFE during the 70-day post-weaning period (Archer, Arthur, Herd, Parnell and Pitchford, 1997), while examination of cow lines has found heifer weaners selected for NFE also display improved NFE as mature cows (Arthur, Archer, Herd, Richardson, Exton, Oswin, Dibley and Burton, 1999).

In a study of beef industry breeding schemes for the NFE trait, Archer and Barwick (2001) assumed genetic correlations between the NFE criterion and the improvement in NFE expressed by young animals to be 0.75 and for mature cows to be 0.50. In this present study these estimates were taken to be the correlations between the estimated breeding value for NFE and the actual improvements in growth efficiency and maintenance efficiency respectively.

Other assumptions regarding the NFE trait included that initially bulls with an EBV for NFE that is 4 per cent superior for NFE could be purchased by a commercial beef producer (Exton *et al*., 2000). Further, an annual improvement in the NFE of the seedstock herd of 0.76 per cent was assumed to be feasible. This was derived from Arthur, Archer, Johnston, Herd, Richardson and Parnell (2001) who found an annual response to selection for an improvement NFE of 0.16 kg/day; however given multiple-breeding objectives, the annual potential rate of progress in the NFE EBV might reasonably be assumed to be only half, or 0.08 kg/day. In the study by Arthur *et al*. (2001), daily feed intake averaged 10.5 kg of dry matter per day therefore a reduction in NFE of 0.08 kg/day is equivalent to a 0.76 per cent improvement in the NFE trait per year.

The rate of improvement in NFE was determined by developing a simple cumulative model based upon fixed proportions of the age cohorts within the commercial cow herd. That is, 19.8 per cent of the cows were in the 2 year old cow cohort, and 17.1 per cent, 14.7 per cent, 12.7 per cent, 11.0 per cent, 9.5 per cent, 8.2 per cent and 7.0 per cent were in the 3 to 9 year old age cohorts, respectively. Additionally, since the herd was a commercial herd it was assumed that the farm manager does not impose additional selection pressure for NFE and that replacement heifers selected for the cow herd are selected on visual type and growth performance. The result is that by year 25 there is a 5.9 per cent reduction in the herd's ME requirement over the base herd.

It should be noted that even within a multi-period LP framework, this methodology will still potentially underestimate the NFE gain achieved in the commercial herd since the fixed cow age cohorts assume a steady state herd. Conversely, a herd that increases in size by retaining additional heifers will have a higher proportion of young animals that will increase the herd's overall NFE improvement. However the effect of this can be limited in the NTMP by including a constraint on the proportion of heifers that can be retained. For example, for a 100 cow herd, 24 heifers would normally need to be retained (pre-culling), under the reproductive assumptions in the NTMP, and 18 surplus heifers sold, that is 57 per cent of heifers are normally retained before culling at 20 months of age. However for the NTMP the proportion of heifers retained each year averaged 62 per cent for the TGM approach and 65 per cent for the net worth approach. Two-year old bulls are available to be purchased from year 1 and replaced every three years over a 25 year period.

This increase in efficiency in the cow herd and growing stock was implemented in the NTLP by altering the parameters reflecting efficiency of utilisation of metabolisable energy for animal maintenance and growth, known as k_m and k_g respectively (SCA, 1990), for each year over 25 years,

where ME requirement = $\frac{NE_m}{k_m} + \frac{NE_g}{k_g} + \frac{NE_c}{k_c} + \frac{NE_l}{k_l}$

and where *ME* refers to metabolizable energy,
NE refers to net energy,
k(subscript) refers to efficiency of use of ME,
m refers to maintenance,
g refers to liveweight gain,
c refers to the products of conception, and
l refers to lactation (SCA, 1990).

5.3 Alternative Versions of the NTMP

Comparisons between the without-NFE case (base) and the with-NFE case, were done using optimal farm plans generated by conducting several modelling experiments varying in complexity.

The whole-farm single-year equilibrium model described in the previous sections provides a method by which to assess the benefits of a technology in a before and after sense, assuming the new technology once made available to the model is selected in the optimal farm plan. This is readily applicable to technologies that are not time dependent, for example a new feed supplement, drench or fertilizer. For example Farquharson (1991) used such a model to assess the use of a hormone vaccination to induce twinning in cattle using this approach. Alford, Griffith and Davies (2003) used the NTLP to assess the on-farm benefits of a potential new technology that increases the growth rates of Northern Tablelands pastures during the winter feed gap.

However, in the case of technologies that have dynamic attributes, measuring the cashflow over time becomes important. Genetic traits in ruminants that have long biological lags are such technologies. Typically, a commercial beef or sheep producer is constrained to purchasing the enhanced genetic trait through buying in superior sires to infuse the desired trait into their commercial breeding herd over time. This means that a single-year equilibrium model will be unable to effectively measure the costs of introducing the new technology over time. In the case of the NFE technology in beef cattle, any herd expansion that is possible as a result of introducing the trait is based on retaining NFE-infused heifers rather than selling them. Thus, the change in herd dynamics has to be properly incorporated as does the opportunity costs of the forgone heifer sales. These herd dynamics can be represented explicitly within a multi-period version of a whole farm LP model, named NTMP. Appendix F details the additional sub-matrices required for the various enterprises in the multi-period model.

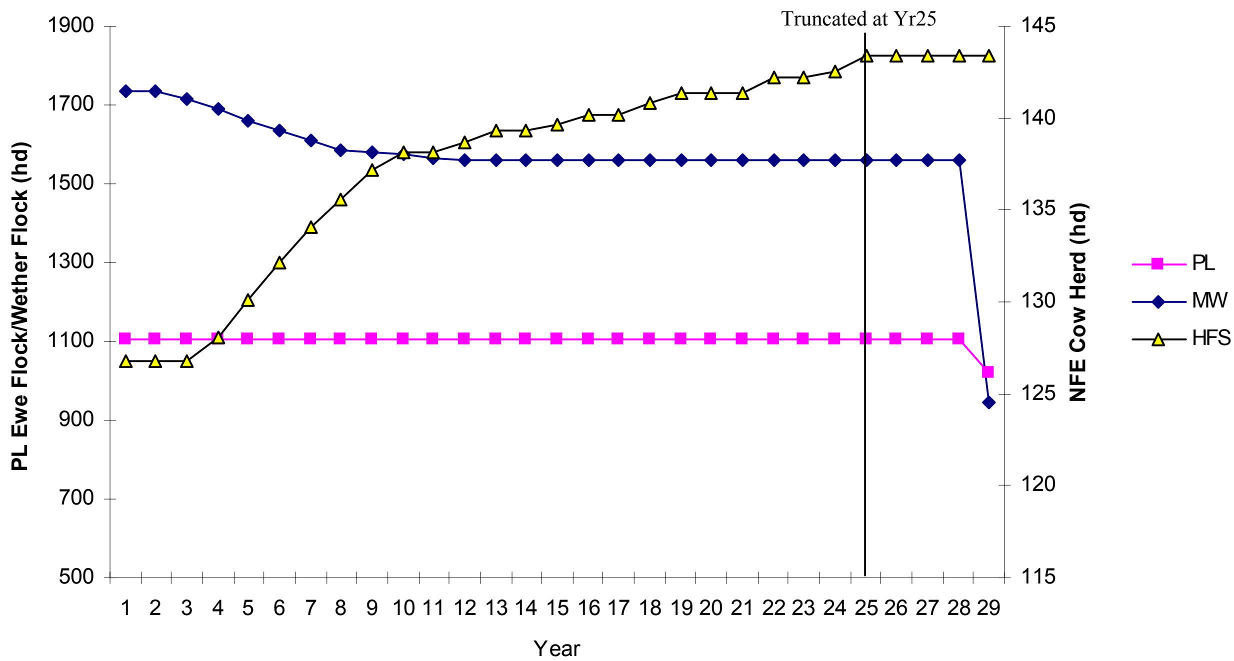
To include the farm manager's decision on the proportion of heifers to retain, additional activities including the sale or retention of heifers are included in the LP framework along with the required constraints. Further, since each age group of cows will have a different level of NFE, these age cohorts were also modelled separately in the LP. Management constraints such as the proportion of mortalities and culls for each age cohort and calving rates remained the same as that described in Appendix A for the heavy feeder steer enterprise.

5.4 Maximising Discounted Total Gross Margins

In the first modelling experiment, NTMP was optimized for the discounted sum of annual total gross margin (TGM) for the representative farm. The model is based upon a 29-year time frame, although only the first 25 years are used for reporting. The optimal farm plan for the base case (without the NFE technology) was 1,108 prime lamb-producing ewes (PL); 1,732 19-micron Merino wethers (MW); and a cow herd of 127 cows (unimproved for NFE) producing heavy feeder steers (HFS). This plan is the same as that reported in Table 11.

In the multi-period LP model, the herd and flock sizes remain constant after year 25, assuming a 5 per cent discount rate (Figure 4), however as the model approaches the terminal year a number of "artificial" adjustments occur in the LP. Some stock are liquidated in year 28 as the LP seeks to maximise the sum of annual TGM. For example, wethers, first-cross ewes and weaner heifers that would normally be retained as replacements are sold off in year 28 to reduce supplementary feeding costs. Therefore to avoid this distortion, the results reported by the model are truncated at year 25.

Figure 4. Changes in herd and flock sizes on the representative farm over 25 years



Next the NFE cow enterprise was included in the model. The NFE improvements were assumed to occur within the first 25 years as described above, and the ME requirements for the NFE cow herd were assumed to remain at the year 25 level of improvement for the years beyond year 25. Further, the initial (year 1) sheep enterprises were set the same as the base case (1,108 prime lamb producing ewes and 1,732 19-micron Merino wethers). Again, the model selected 127 HFS producing cows, however in Year 1 NFE bulls were selected to put over the cow herd.

Thus, the optimal farm plan (Table 13) is to invest in the new technology by purchasing the NFE-superior bulls and expanding the cow herd while concurrently decreasing the scale of the Merino wether enterprise. Substitution of Merino wethers for NFE cows occurs up to year 12 after which additional breeding cows are possible from their increasing net feed efficiency alone (Figure 4).

Table 13. Optimal farm plan for a without (Base) and with-technology (NFE) farm in year 25

Enterprise	*Unit*	*Base*	*NFE*
Prime Lamb	Ewes	1,108	1,108
Merino Wethers	Wethers	1,732	1,560
Unimproved Cow Herd	Breeding cows	127	-
NFE Cow Herd	Breeding cows	-	143
Objective Function[1]	$	1 202 635	1 211 275
PV (including livestock [2])	$	1 264 133	1 280 029
Difference in NPV	$	-	15 896
Difference in NPV / breeding cow/year (NPV/127cows/25 years)			$5.02

[1] Present value of accumulated Total Gross Margins discounted at 5 per cent.
[2]Salvage value assumptions regarding livestock assets of the farm plan include slaughter values for the different classes of livestock including breeding units (including followers) Prime Lamb, $36.40/unit; Merino wethers, $22.08/unit and unimproved cows, $979/unit and NFE cows at year 25 valued at $1,068/unit (refer to Appendix A for further details). A premium for NFE cows and heifers was assumed to be 11.8 per cent above unimproved cows based upon the differential assumed by Exton *et al*. (2000).

Over the whole planning horizon, the various livestock enterprises adjusted so that by year 25 the optimal farm plan was 1,108 prime lamb producing ewes, 1,560 19-micron Merino wethers and a herd of 143 NFE cows. This was an increase in cow numbers of 12.6 per cent by year 25 (Table 13). This equated to an improvement in the NPV per breeding cow per year over the base herd of $5.02, using a 5 per cent discount rate.

This compares with the calculated NPV per breeding cow per year estimated by Exton *et al.* (2000) of $6.95, and an increase of 10 per cent in cow numbers. The LP approach allows for input substitution, where resources are diverted away from the Merino wether enterprise towards the new NFE cattle enterprise, resulting in greater growth in cow numbers compared to that estimated by the fixed enterprise assumptions of the cash flow model. This result, while specific to the Northern Tablelands case, demonstrates the additional benefits of an LP in valuing the impact of a new technology at the farm level including the potential level of adoption.

It should be noted that this analysis does not assume that there is a premium paid for young cattle sold to feedlots on the basis of improved NFE. The potential for a premium being paid for NFE stock by feedlotters needs to be determined from an analysis of the feedlot sector.

Further, additional information provided by the LP shows that the NFE technology might be of particular benefit in grazing regions where there typically exists high variability in pasture growth within the year. For example, on the Northern Tablelands, where a significant pasture feed shortage occurs in winter (Ayres, Dicker, McPhee, Turner, Murison, and Kamphorst, 2001), potential costs savings might be achieved through better matching feed supply and feed demand and thereby reducing supplementary feed costs. That is, winter feed has a higher opportunity cost than at other times of the year.

The area of perennial pasture is fixed in the model and is therefore treated as a constraint. Table 14 shows a selection of pasture constraints in the model and the shadow prices of bound constraints. The higher shadow prices for the area of perennial pasture with the NFE technology available in year 1 and year 25 ($264.19/ha and $26.76/ha respectively) compared with the base case for year 1 and year 25 ($54.64 and $14.90/ha respectively) reflect the greater marginal productivity that can be attained by use of the NFE technology. This is also evident in the shadow prices indicated for pastures during the winter months on the representative farm. As can be seen in the table, energy from the perennial pasture is a binding constraint in both models. In July, for example, the shadow price for perennial pastures with the NFE technology is considerable higher ($0.029/MJ ME) than for the case when the technology is unavailable ($0.007/MJ ME). Pannell (1999) describes the phenomenon of higher shadow prices for feeds as a result of seasonal fluctuations in pasture growth.

Table 14. Comparison of some binding constraints in the linear program solutions for the with NFE and without farm scenarios

Constraint		Unit	Binding (B) or Slack (S)		Shadow Price[1]	
			NFE	Base	NFE	Base
Yr 1	Perennial pasture Area	ha	B	B	264.19	54.64
Yr 25	Perennial pasture Area	ha	B	B	26.76	14.90
Yr 1	Perennial pasture June	MJ ME	B	B	0.019	0.005
Yr 1	Perennial pasture July	MJ ME	B	B	0.029	0.007
Yr 1	Perennial pasture August	MJ ME	B	B	0.049	0.012

[1] 5 per cent discount rate used.

5.5 Effect of Discount rate

The appropriate discount rate is subjective and depends in part upon the opportunity cost of the money invested in the project. Given the long-term nature of the breeding activities on this representative farm, a discount rate of 5 per cent was used in the calculation of net present values. This is the same rate as that used by Exton *et al.* (2000) and is similar to the 10 year Australian Treasury bond rate for 2000/01 of 5.8 per cent (ABARE, 2003). In a series of studies done for an external review of research activities in NSW Agriculture (eg. Griffith *et al.*, 2004), a 4 per cent discount rate was used.

The discount rate used influences the level of investment in the NFE technology on the representative farm with a higher discount rate resulting in a lower investment in NFE cattle over the 25 year period (see Figure 5). Conversely, at a rate of 3 per cent the optimal NFE beef herd size is 157 cows by year 25 compared with 143 cows and 135 cows at year 25 when using 5 per cent and 7 per cent discount rates respectively.

5.6 Maximising Farm Net Worth

In the second series of experiments, NTMP was optimized for the net worth of the representative farm at the end of the selected planning horizon. Thus the whole-farm model has to include not only the annual total gross margin (TGM), but also fixed costs and family drawings, an overdraft debt facility, an off-farm investment activity (Table 15), and a value for the livestock assets on hand at the end of the planning horizon. Such a specification allows for examination of the effect of capital constraints on uptake of the NFE technology by use of borrowed capital and the reinvestment of own savings into the farm. Typical values for

Figure 5. Effect of discount rate used on the optimal beef herd size

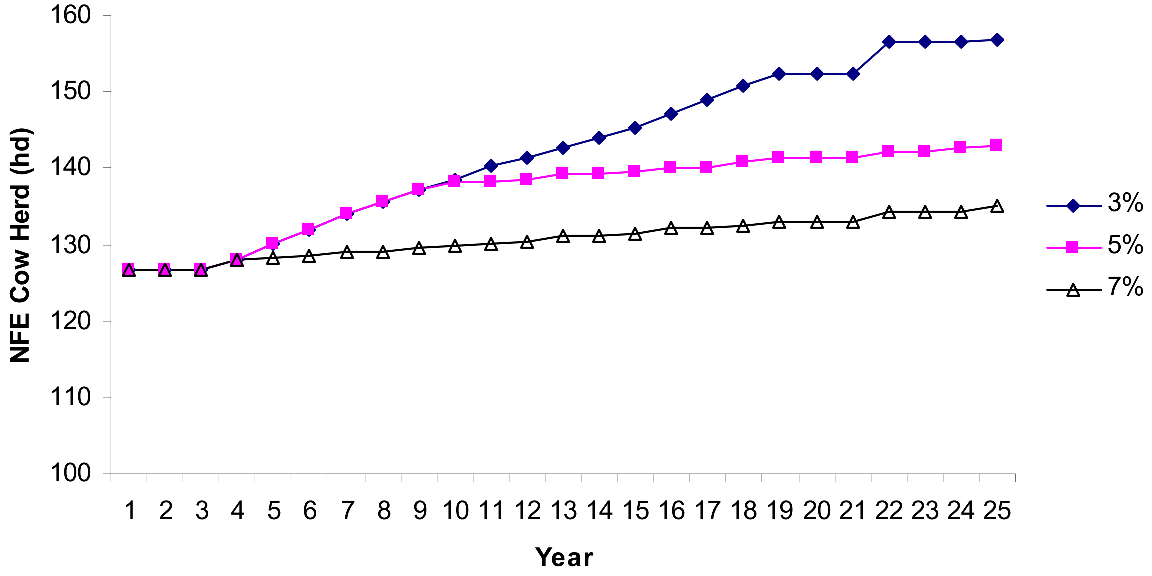


Table 15. Assumed whole-farm budget components

Overheads + Depreciation ($)	39 000
Family drawings ($)	35 000
Credit interest rate (%)	0.04
Overdraft interest rate (%)	0.11
Overdraft Account limit ($)	50 000
Value of Plant and Land ($)	1 254 000

overdraft amounts were determined from ABARE survey data for the region and from several cooperating district farmers, while interest rates were determined from Reserve Bank of Australia data (RBA, 2003a,b). The average overdraft for small business in 2001 was 9.5 per cent, and an additional 1.5 per cent was added to this amount to reflect the risk premium that is normally associated with rural loans. An income tax component reflecting the progressive tax scale applicable to personal income tax in Australia is included in the model. Additional levies and the treatment of capital gains associated with the Australian taxation system are not considered in this model. Table 16 provides an overview of the various constraints and activities associated with the financial sub-matrix. The financial sub-matrix contains some elements from treatments by Dent *et al.* (1986) and Kingwell and Pannell (1987).

Overheads are incorporated into the model using an overhead activity (*OHS*) and associated constraint (*OHSc*), which includes fixed costs as detailed in Alford *et al.* (2003) and an assumed amount of $35,000 for family drawings. The NTMP includes a taxable income activity (*Taxable I*) and an associated constraint (*Taxable Ic*). *Taxable Ic* includes the income from enterprise incomes and returns from off-farm investment and enterprise gross margin costs, overdraft interest charges as well as that portion of the overheads, that is the fixed costs, which are assumed to be tax deductible. This taxable income activity is then subject to a progressive taxation scale, which includes the activities *Tax0*, *Tax17*, *Tax30*, *Tax42*, *Tax47* and a net income (*NI*) activity. Related constraints include *Tax6000*, *Tax20000*, *Tax50000* and *Tax60000* which are set at less than or equal to the income amounts for which the different tax scales apply; a *Taxcalc* row which is an equality set to 1 to constrain the tax activities selected to match the progressive tax scale, and a net income (*NIc*) constraint which equates taxable income to the sum of tax and net income (*NI*) activities.

A surplus constraint shows the amount of tax that must be paid in the tax paid activity (*Tax*). The cashflow row then incorporates the outward flow of funds from the farm business in the year including enterprise costs, overdraft interest charges (*Accum OD*), all overheads including family drawings, tax paid and any surplus. This outflow of funds is matched by the inward flow of funds via the cashflow constraint which includes enterprise incomes, interest from savings (*Accum Sav*), the current year's overdraft drawings (*Current OD*) less an interest charge, and re-investment on farm (*Reinvest OF*) from the farmer's accumulated savings from previous years. The remaining surplus activity (*Surplus*) can then be transferred via the surplus use constraint to either of two activities, to accumulated savings (*Surp to sav*) or to retire outstanding overdraft in the following year (*Surp to OD*). The maximum level of overdraft available to the farm business is set using the overdraft limit constraint where the sum of previous year's drawings (*Accum OD*) and the current year's overdraft drawings (*Currrent OD*) is an inequality less than or equal to $50,000.

To link the financial sub-matrix between years, two transfer rows are included in the NTMP. These are shown in Table 17. The first is a transfer overdraft row (*Transfer OD*). This transfers the current year's accumulated overdraft (*Yr t Accum OD*), in addition to any current year's overdraft drawings (*Yr t Current OD*), less any repayment activity (*Yr t Surp to OD*) in the current year, to the next year's accumulated overdraft (*Yr t+1* Accum OD). Similarly savings are transferred between years (*Transfer Sav*). That is, the accumulated savings (*Yr t Accum Sav*) from the current year, in addition to any surplus (*Yr t Surp to sav*) from the current year, are transferred to the next year's accumulated savings off-farm (*Yr t+1 Accum Sav*) or to reinvest on-farm (*Yr t+1 Reinvest OF*).

Since any savings or debts are transferred through the planning horizon within the model, the objective function for the NTMP is simply the maximisation of net worth in the final year (year 25). This is equivalent to the sum of the value of land, plant and machinery in year 25 (Table 15), the value of livestock assets in that year, accumulated savings (*Accum sav*) and surplus activity (*Surplus*) in the final year, less any accumulated overdraft (*Accum OD*) remaining and overdraft drawings (*Current OD*) activity in the final year.

The farm net worth model was initially run without including any salvage value for the livestock (similar to the model when set to maximise the sum of annual TGM). In this case, the optimal farm plan included 138 NFE cows compared with 143 NFE cows using the maximised TGM approach. This reduction in the optimal size of the cow herd reflects the capital constraint imposed by the inclusion of the overhead, capital and family drawing constraints.

Then a salvage value, set at 1.5 times livestock values, was included in the NTMP model to maximise net worth at the end of the 25-year planning horizon. In the base case, the same livestock enterprises as previously described were selected. In the with-technology case, NFE was selected over the entire cow herd and progressively expanded so that by year 25 the NFE herd contains 182 breeding cows, an increase of 43 per cent over the base herd.

Table 16. Representation of the financial sub-matrix

		*Enterprise GM costs**	Accum. OD	Accum Sav	OHS	Taxable I	Tax0	Tax17	Tax30	Tax42	Tax47	NI	Surplus	Current OD	Reinvest OF	Surp to Sav	Surp to OD	*Livestock commodity outputs**	sign	RHS
units		$	$	$	$	$	$	$	$	$	$	$	$	$	$	$	$	$		
OD limit	$		1											1					≤	50000
OHSc	$				1														=	1
Taxable Ic	$	*a*	0.11	-0.04	39000	1								0.11				-*a*	=	
Tax6000	$						1												≤	6000
Tax20000	$							1											≤	14000
Tax50000	$								1										≤	30000
Tax60000	$									1									≤	10000
Taxcalc	$					-1	1	1	1	1	1								=	
NIc	$					1		-0.17	-0.3	-0.42	-0.47	-1							=	
Cashflow		-*a*	-0.11	0.04	-74000			-0.17	-0.3	-0.42	-0.47		-1	0.89	1			*a*	=	
Surp. use													1			-1	-1		=	

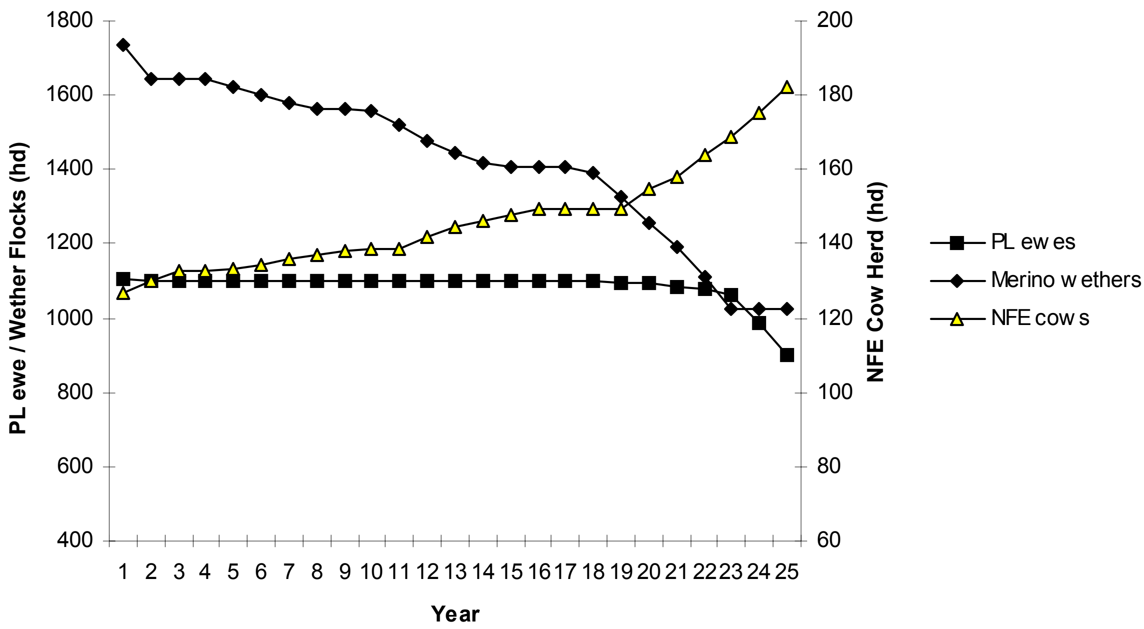
*Enterprise GM costs and commodity output activities are abbreviated to single activities to reduce table size here.

Table 17. Representation of the inter-year transfer ties for the financial sub-matrix

		Yr t Accum OD	Yr t Accum sav	…	Yr t Current OD	Yr t Reinvest OF	Yr t Surp to Sav	Yr t Surp to OD	Yr t+1 Accum OD	Yr t+1 Accum sav	…	Yr t+1 Current OD	Yr t+1 Reinvest OF	sign	RHS
Unit		$	$	$	$	$	$	$	$	$	$	$	$		
Transfer OD	$	1			1			-1	-1					=	0
Transfer sav	$		-1				-1			1			1	=	0

Some key output for the representative farm is provided as an example (Figure 6 and Table 18). As the cattle enterprise is expanded, the prime lamb enterprise decreases in size from 1,108 ewes to 1,101 ewes by year 18 and then to 902 ewes by year 25, while the Merino wether enterprise decreases from the initial 1,732 wethers to 1,025 wethers by the final year. The final difference in net worth of the farm business with the NFE technology compared to the base case is $80,509, or $634 per breeding cow (based upon the original 127 cow herd).

Figure 6. The optimal farm plans over time with the NFE technology and with overhead, capital and family drawing constraints



Terminal valuations of the livestock assets were initially set at their equivalent cull prices with an 11.8 per cent premium attached to the NFE cows following Exton *et al.* (2000). However a range of terminal asset prices for the livestock were used to test the sensitivity of the evaluation results to these assumptions (see Table 19).

Table 18. Results when optimising net worth

	$
Net Worth, with NFE available	1 683 637
Net Worth, without NFE	1 603 128
Change in Net Worth	80 509
Net worth improvement per cow (original herd size)	634
Terminal value assumptions:	
Land, plant and machinery	1 254 000
NFE Cows	1 602
Unimproved cows	1 469
Prime Lamb ewes	54.60
Merino wethers	33.12

Livestock values are x 1.5 cull salvage price (including followers) and 11.8 per cent premium attached to NFE cows

Terminal values were chosen based on multiplying (×1.0, ×1.25, ×1.5, ×1.75, ×2.0) the salvage value of the animals, including followers, these are detailed in Appendix A. The results discussed in Table 18 use terminal values based on a multiple of 1.5. The results of the sensitivity analysis for terminal asset values (Table 19) indicate that the change in net worth attributed to the NFE technology increases with increasing terminal value of the livestock assets. This is attributable to the model increasing the optimal size of the NFE herd as the terminal value increases. At the highest terminal values tested (×2.0) the optimal herd size is 184 cows, an increase of 45 per cent over the base herd size. This compares with a 38 per cent increase in herd size when the terminal value is equivalent to cull prices, and a 12 per cent increase in herd size when only the total gross margin was optimised.

The sensitivity of the whole farm plan to terminal valuations of livestock assets, and therefore the extent of adoption of this technology on the representative farm, highlights a complexity in models that incorporate long planning horizons. This has implications for analysis of this NFE technology in the Northern Tablelands representative whole-farm LP. As also seen with models assessing long-term environmental issues, the optimal results can be artificially affected by the valuation of assets in the distant future, known as the "age effect". Boussard (1971) using linear programming models for long-term farm planning identified this problem whereby decisions in the early planning periods are strongly influenced by the final value of the commodities being modelled. One method that can be used by modellers to address this problem is to extend the planning horizon and essentially disregard results in latter periods.

The incorporation of debt along with farm overhead costs, tax and family living expenses is also illustrated in this modelling experiment. Using the assumptions in Table 19 and an exogenously incorporated starting overdraft debt of $20,000, it was found that the optimal farm plan by year 25 would have a reduced investment in NFE cows. Only 171 breeding cows (a 35 per cent increase in herd size over the base herd) would be optimal compared with 182 cows (or 43 per cent increase) under the assumption of no initial debt at the start of the modelling time frame. As expected, debt servicing is found to reduce the capacity of the farm business to adopt the NFE technology.

5.7 Post-Optimality Risk Analysis

The degree of risk and attitudes to this risk influence the adoption of technologies by farmers. A benefit of the whole-farm linear programming methodology in the economic evaluation of agricultural technologies at the farm-level is the ability to extend the model to incorporate risk by stochastic programming (Hardaker, Huirne and Anderson, 1997), although such approaches may not be practically applied to large multi-period models. Further, the development of stochastic mathematical programming assumes that the incorporation of risk into the model will more accurately evaluate the extent of adoption of a new technology within a farm system by more closely matching the farmer's decision-making priorities. Whether this might always be the case is questioned by Pannell, Malcolm and Kingwell (2000, p.75) (see section 2.2.3 above).

One method of analysing risk that has been applied to deterministic models has been to undertake simulations by using @Risk™ (Palisade Corporation, 2001). This software allows price distributions for key variables to be incorporated into the budgets derived from the optimal farm plans (see for example, Farquharson, 1991). In this section a preliminary post-optimality risk analysis is undertaken, based on probability distributions of the prices used in the model. This analysis is based on the first version of the NTMP, where the NPV of TGM is maximised.

Table 19. **The change in farm net worth and optimal plan for different terminal asset prices**

	Terminal value 1		Terminal value x 1.25		Terminal value x 1.5		Terminal value x 1.75		Terminal value x 2	
	Base	NFE	Base	NFE	Base	NFE	Base	NFE	Base	NFE
Net Worth ($m)	1.499	1.5556	1.551	1.620	1.603	1.684	1.655	1.748	1.707	1.813
Change in Net Worth ($)		56 456		68 426		80 508		93 149		106 105
Change in Net Worth per cow ($)		445		538		634		733		835
Optimal Enterprise Mix in Year 25										
NFE Cattle (cows)		176		179		182		184		184
Prime Lambs (ewes)		1 057		979		902		866		865
Merino wethers (head)		918		971		1 025		1050		1 051
Effect of Debt on Optimal Enterprise Mix in Year 25										
NFE Cattle (cows)						171				
Prime Lambs (ewes)						1 072				
Merino wethers (head)						996				

New South Wales monthly price data over the period 1991 to 2001, for the livestock classes selected in the optimal farm plan, were examined (AMLC, 1997; MLA, 2001). All prices were adjusted to 2001 dollars. A similar time frame (post the abandonment of the Wool Reserve Price Scheme) was used to determine the wool price distribution. The wool prices used were the average of the minimum, median and maximum annual clean price for the relevant microns (19 and 28 microns) from Wool International and Australian Wool Exchange (ABARE, 2000; Wesfarmers Landmark, 2002).

The general triangular (@TRIANG) probability distribution was chosen, which necessitated selecting minimum, maximum and most likely prices (Table 20). Simulations using these distributions were undertaken on the optimal plans for both the without- and the with-NFE plans. Correlations were applied between the various cattle prices, between the various sheep prices, and between the sheep and cattle prices. Wool prices were assumed to be independent of livestock prices for the purposes of this modelling exercise. While the rank-order correlations used in @Risk are not equivalent to correlation coefficients, correlation coefficients were determined from the price series data for the various outputs (Table 21) to assist in attributing rank order correlations. The rank order correlations used in @ Risk were 0.7 between beef cattle prices, 0.5 between the various sheep prices and 0.4 between the sheep and cattle prices. A correlation of 0.4 was also applied between the 19-micron and 27-micron wool prices.

An examination of the simulation results summary (Table 22) and the resulting cumulative distribution functions (Figure 7) suggests that the without-technology plan in year 25 has a lower average total gross margin, a lower minimum total gross margin and a more variable total gross margin. The cumulative distribution function (CDF) diagram indicates that the without-technology plan is dominated by the with-NFE farm plan using the first-degree stochastic dominance criterion. Therefore, the optimal farm plan incorporating the NFE technology does not increase income risk from output price variability. The minor difference in the CDFs shown in Figure 7 would be anticipated given the positive correlations that were included in the risk modelling exercise between the cattle and sheep livestock prices. Further the optimal farm plan still remains relatively diversified with 31 per cent of livestock on a dse basis being allocated to the prime lamb enterprise, 15 per cent to Merino wethers and 53 per cent to NFE cows. This compares with the base case of 37 per cent of dse's allocated to the prime lamb enterprise, 25 per cent to Merino wethers and 38 per cent of total dse's being allocated to the HFS cattle enterprise.

However, the application of risk analysis to such long-term analyses is problematic, given the enormous variability in climatic and biological components of the whole farm. These issues are not addressed here.

Table 20. Examples of price distributions used in the risk model

Price variable	Distribution	Price variables (minimum, most likely, maximum)	
18 m.o HFS steer	Triangular	103, 158, 203	c/kg lw
9 m.o weaner heifer	Triangular	75, 142, 198	c/kg lw
Cull cows	Triangular	108, 203, 284	c/kg dw
Prime lambs	Triangular	53, 98, 151	c/kg lw
Wethers	Triangular	5, 35, 77	c/kg lw
19 micron wool	Triangular	760, 1013, 1491	c/kg clean
28 micron	Triangular	479, 538, 692	c/kg clean

Table 21. Correlation coefficients between various livestock output prices from the representative farm*

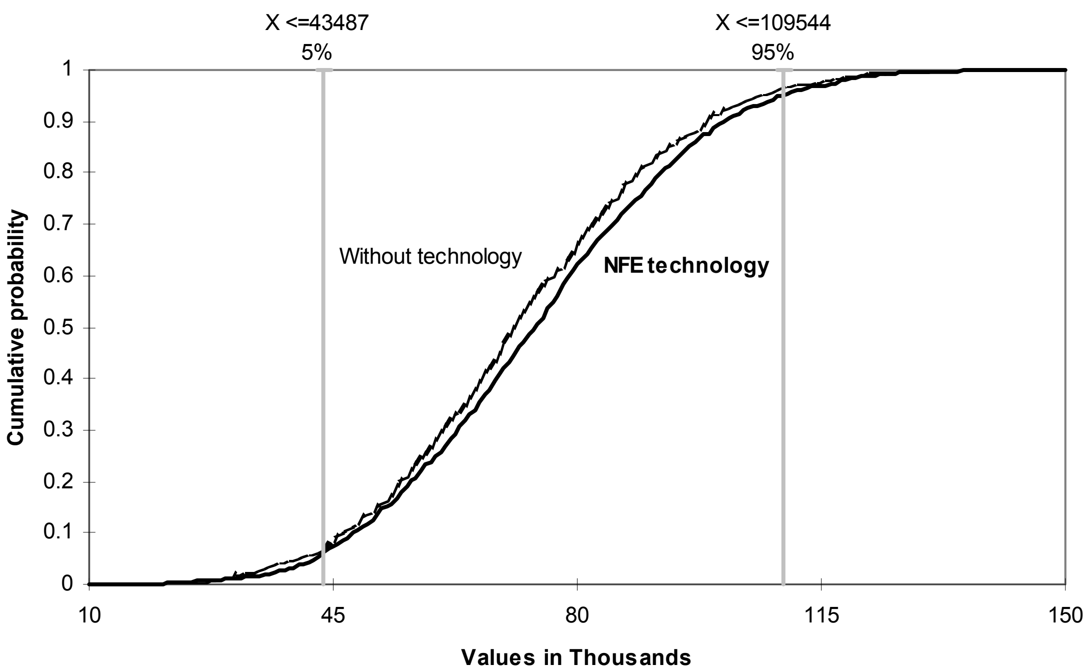
	Cows 22 – 26	Young cattle to 20	Lambs 8-16	Wethers 8-22
Cows 22 - 26	1	0.66	0.14	0.33
Young cattle to 20		1	0.41	0.49
Lambs 8-16			1	0.54
Wethers 8-22				1

*Correlations based on NSW monthly price data, 1991 to 2001 (MLA, 2000)

Table 22. Summary results of @Risk simulation for Year 25 results

Distribution measure	Without- technology Plan ($)	With NFE technology ($)
Mean	72 688	75 059
Minimum	14 123	21 191
Maximum	135 813	138 700
Standard Deviation	20 044	20 467

Figure 7. Comparison of the cumulative distribution functions for without- and with-NFE Technology optimal farm plans based upon the total gross margin in Year 25 of the optimal farm plans



6. Conclusions

The benefits of evaluating a new technology in a whole-farm context using a linear programming framework are well known. Compared to using an enterprise gross margin approach, linear programming provides an optimal farm plan rather than a variation on the current farm plan. Further, it allows the joint evaluation of concurrent farm activities, while considering the costs and returns of all enterprises and any resource adjustments imposed by adoption of the technology (Griffith *et al.,* 1995). In the type of farming system modelled here, a mixed grazing farm on the Northern Tablelands of New South Wales, the whole-farm focus incorporates various aspects of the pasture base, resource constraints and sheep and cattle interactions.

In this Report, an overview of economic tools that are available to assess technologies at the farm level is provided first, listing some of the major benefits and limitations of each of these various techniques. A representative farm for the selected farming system is then developed and a whole-farm linear program based on this representative farm (NTLP) is described in some detail. A series of modelling experiments is undertaken to examine variations of the base model and their impact on the resulting technology evaluation. An example technology, involving the genetic improvement of beef cattle for improved feed efficiency (NFE), is evaluated.

The optimal farm plan for a "typical" (single) year is generated from NTLP, given the objective of maximising farm total gross margin. Three enterprises are selected: 1,108 first-cross ewes, 1,732 Merino wethers and a beef herd of 127 cows producing 18 month old steers at 448kg liveweight and excess heifers sold as 9 month old weaners. For this farm plan, the annual operating budget shows a total gross margin for the farm of $86,191.

The optimal farm plan for the representative farm is found to be sensitive to relatively small changes in input or output prices and production parameters. Only small improvements in a number of the individual enterprise gross margins would result in them displacing the currently selected enterprises. These results suggest relatively similar profitability levels between these sheep and beef enterprises, and a relatively constant TGM across different enterprise combinations. This would be anticipated given that all the enterprises described in this report were identified by local experts as being common in the Northern Tablelands. Further, the relatively small differences in enterprise profitability when viewed in a whole farm context also reflect the similar resources that each of the enterprises require, making them readily substitutable. These results do not support a strategy of frequently changing the enterprise mix in this farming system.

For new technologies that have dynamic attributes, measuring the cashflow over time becomes important. Genetic traits in ruminants that have long biological lags are such technologies. This means that a single-year equilibrium model will be unable to effectively measure the costs of introducing the new technology over time. In the case of the NFE technology in beef cattle, any herd expansion resulting from selection for the NFE trait requires heifers to be retained instead of sold. These herd dynamics can be represented explicitly within a multi-period version of a whole-farm LP model (NTMP).

The NFE cow enterprise is offered to the NTMP model, with the initial sheep enterprises set the same as the base case (1,108 prime lamb producing ewes, 1,732 19-micron Merino wethers). The model again selects 127 HFS producing cows in the first year, but the new optimal farm plan is to invest in the new technology by purchasing NFE-superior bulls in successive years and expanding the cow herd while concurrently decreasing the scale of the Merino wether enterprise. Substitution of Merino wethers for NFE cows occurs up to year 12 after which additional breeding cows are possible from their increasing net feed efficiency alone. There is an increase in cow numbers of 12.6 per cent by year 25, which equates to an improvement in the NPV per breeding cow per year over the base herd of $5.02, using a 5 per cent discount rate. Other experiments reported include adding constraints for fixed costs, family drawings and an overdraft facility; alternate discount rates for the NPV calculations; alternate terminal values for the livestock assets at the end of the simulation period; and a post-optimality risk analysis.

This study has highlighted several additional benefits of evaluating a technology in a whole farm multi-period linear programming framework. First, apart from determining the type and size of the optimal farm enterprise mix and the optimal value of the objective function, whole-farm multi-period linear programming also provides important additional information including shadow costs and prices and constraint slacks (Pannell, 1997), and how they change over time. Shadow costs of activities show how sensitive the optimal farm enterprise mix is to changes in the gross margins of alternate farm activities not included in the current farm plan. The shadow prices for resources indicates how much a farm manager could pay for additional units of a limiting resource, for example, additional labour.

Second, in terms of the specific NFE technology examined in this report, it would appear that there may well be regions where such feed efficiencies may be of greater benefit due to particularly large variations in pasture growth patterns throughout the year. The Northern Tablelands with its recognized winter feed deficit may be one such area. This information may be of benefit to researchers in extending the NFE technology to farmers.

Third, the deterministic multi-period model highlighted the impact of the inclusion of overhead and capital constraints in the modelling process in determining the potential adoption of a technology by a farm manager. The availability and cost of capital is shown to influence the extent to which the NFE technology may be adopted by an individual farm business.

Fourth, from a modelling perspective, the effect of uncertain terminal values and the bearing that they have on measuring the level of adoption of a new technology is an area for further investigation.

Finally, the impact of risk was assessed in this study post-optimally by the inclusion of stochastic output prices in the optimal whole farm budgets. This is an area for further research, including the potential of alternate modelling techniques such as MOTAD programming or stochastic dynamic programming. However due to size constraints, such approaches may necessitate trade-offs in terms of the detail of whole-farm models to which they are applied.

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APPENDIX A

Production Parameters for Livestock Enterprises and Associated Labour Requirements

Enterprise : **Cross-bred vealer production**

Enterprise unit: 100 cows

Calving date		July – August
Weaning rate		86%
Sale weights	- steers 9-10 m.o.	290 kg lw April-May
	- heifers 9-10 m.o.	270 kg lw April-May
Adult mortality		2%
Calf mortality		5%
Bull requirement		3%
Bull cull rate		33%
Cows	- age at first calving	2 yrs
	- cull for age	10 yrs
	- average liveweight	500 kg
	-liveweight range	460kg at joining to 530kg at calving
Growth rates	- calves winter/summer	0.8 kg/day
	- calves spring/autumn	1.0 kg/day

Vealer production (labour hours per 100 cows)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Calving							20	20				
Marking/ Drench/Vacc.											20	
Vaccinate												20
Marketing			40	20	20							
Supervision	23	23	23	23	23	30	30	30	30	30	30	23
Total	23	23	63	43	43	30	50	50	30	30	50	43

Salvage value of a 100 cow herd assumes stock remaining after normal stock sales (including cfa cows) during the year are sold at the end of the production year, hence livestock numbers reflect mortalities over 11 months

Livestock class (hd)	Weight (kg)	Price ($/kg)	Price per head ($)	Total ($)
89.2 cows	250 (d.w.)	2.56 (d.w.)	640	57 088
18 Heifers (24 m.o.)			800	14 400
2.5 Bulls	450 (d.w.)	2.66 (d.w.)	1 197	2 993
				74 481
			100 cow herd	
		Per breeding unit		**$745**

For further information refer to the livestock enterprise budgets detailed in Alford *et al*. (2003).

Enterprise : **Weaner production**

Enterprise unit: 100 cows

Calving date		August-September
Weaning rate		82%
Sale weights	- steers 9 m.o.	270 kg lw April-May
	- heifers 9 m.o.	240 kg lw April-May
Adult mortality		2%
Yearling mortality		3%
Calf mortality		5%
Bull requirement		3%
Bull cull rate		33%
Cows	- age at first calving	2 yrs
	- cull for age	10 yrs
	- average liveweight	475 kg
	-liveweight range	440kg at joining to 490kg at calving
Growth rates	- calves winter/summer	0.7 kg/day
	- calves spring/autumn	0.9 kg/day
	- yearlings	0.5 kg/day

Weaner production (labour hours per 100 cows)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Calving								20	20			
Marking/ Drench/Vacc.												20
Vaccinate	10											
Marketing				10	10							
Weaning				7	7							
Supervision	23	23	23	23	23	30	30	30	30	30	30	23
Total	33	23	23	40	40	30	30	50	50	30	30	43

Salvage value of a 100 cow herd assumes stock remaining after normal stock sales (including cfa cows) during the year are sold at the end of the production year, hence livestock numbers reflect mortalities over 11 months

Livestock class (hd)	Weight (kg)	Price ($/kg)	Price per head ($)	Total ($)
89.7 cows	228 (d.w.)	2.56 (d.w.)	584	52 385
23 heifer calves (12 m.o.)	275 (l.w.)	1.57 (l.w.)	431	9 913
19 Heifers (24 m.o.)	212 (d.w.)	2.56 (d.w.)	543	10 317
2.5 Bulls	450 (d.w.)	2.66 (d.w.)	1 197	2 993
			100 cow herd	75 608
			Per breeding unit	**$756**

For further information refer to the livestock enterprise budgets detailed in Alford *et al*. (2003).

Enterprise : **Young Cattle (moderate growth) production**

Enterprise unit: 100 cows

Calving date		August-September
Weaning rate		84%
Sale weights	- steers 20 m.o.	460 kg lw April-May
	- heifers 18 m.o.	390 kg lw April-May
Adult mortality		2%
Yearling mortality		3%
Calf mortality		5%
Bull requirement		3%
Bull cull rate		33%
Cows	- age at first calving	2 yrs
	- cull for age	10 yrs
	- average liveweight	475 kg
	-liveweight range	440kg at joining to 490kg at calving
Growth rates	- calves winter/summer	0.65 kg/day
	- calves spring/autumn	0.80 kg/day
	- yearlings	0.80 kg/day

Young cattle production (labour hours per 100 cows)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Calving								20	20			
Marking/ Drench/Vacc.												20
Vaccinate	10											
Marketing		5		15								
Weaning			15									
Supervision	23	23	23	23	23	30	30	30	30	30	30	20
Total	33	28	38	38	23	30	30	50	50	30	30	40

Salvage value of a 100 cow herd assumes stock remaining after normal stock sales (including cfa cows) during the year are sold at the end of the production year, hence livestock numbers reflect mortalities over 11 months

Livestock class (hd)	Weight (kg)	Price ($/kg)	Price per head ($)	Total ($)
90.7 cows	228 (d.w.)	2.56 (d.w.)	584	52 967
42 steer calves (12 m.o.)	285 (l.w.)	1.67 (l.w.)	476	19 992
42 heifer calves (12 m.o.)	275 (l.w.)	1.57 (l.w.)	431	18 102
22.1 Heifers (24 m.o.)	212 (d.w.)	2.56 (d.w.)	543	12 000
2.5 Bulls	450 (d.w.)	2.66 (d.w.)	1 197	2 993
			100 cow herd	106 054
			Per breeding unit	**$1 060**

For further information refer to the livestock enterprise budgets detailed in Alford *et al*. (2003).

Enterprise : **Heavy feeder steer production**

Enterprise unit: 100 cows

Calving date		August-September
Weaning rate		84%
Sale weights	- steers 18 m.o.	450 kg lw April-May
	- heifers 9 m.o.	240 kg lw April-May
Adult mortality		2%
Yearling mortality		3%
Calf mortality		5%
Bull requirement		3%
Bull cull rate		33%
Cows	- age at first calving	2 yrs
	- cull for age	10 yrs
	- average liveweight	475 kg
	-liveweight range	440kg at joining to 490kg at calving
Growth rates	- calves winter/summer	0.65 kg/day
	- calves spring/autumn	0.80 kg/day
	- yearlings	0.50 kg/day

Heavy feeder steer production (labour hours per 100 cows)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Calving								20	20			
Marking/ Drench/Vacc.												20
Vaccinate	10											
Marketing		10				5						
Weaning			15									
Supervision	23	23	23	23	23	28	28	28	30	30	30	23
Total	33	33	38	23	23	33	28	48	50	30	30	43

Salvage value of a 100 cow herd assumes stock remaining after normal stock sales during the year are sold at the end of the production year, hence livestock numbers reflect mortalities over 11 months

Livestock class (hd)	Weight (kg)	Price ($/kg)	Price per head ($)	Total ($)
90.7* cows	228 (d.w.)	2.56 (d.w.)	584	52 969
38.5 steer calves (12 m.o.)	310 (l.w.)	1.67 (l.w.)	518	19 943
22.8* heifer calves (12 m.o.)	280 (l.w.)	1.57 (l.w.)	440	10 032
22.1 Heifers* (24 m.o.)	212 (d.w.)	2.56 (d.w.)	543	12 000
2.5 Bulls	450 (d.w.)	2.66 (d.w.)	1 197	2 993
			100 cow herd	97 937
			Per breeding unit	**$979**

* A 11.8% premium is added to female stock to determine NFE stock value at year 25, following Exton *et al*. (2000). This is equates to $1068/bu for NFE stock. For further information refer to the livestock enterprise budgets detailed in Alford *et al*. (2003).

Enterprise: **Self-replacing Merino flock - 19 micron**

Lambing date		September-October
Weaning rate		80%
Mortality	- adult	3%
	- hogget	3%
	- lamb	5%
Ram requirement		2%
Ram cull rate		25%
Ewes	-culled for age	5.5 yrs
	- average body weight	45 kg
Hoggets	- sold	1.5 yrs
Shearing date	- pre-lamb	August

Self-replacing Merino flock (labour hours per 1000 ewes)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
shearing								60				
crutching			25									
drenching	20		20		10					20	20	20
marking											40	
insp. & muster	17	17	17	17	17	17	17	17	17	17	17	17
lamb supervision									25	25		
fly control				15								15
classing &cull		20										
Total	37	37	62	32	27	17	17	77	42	62	77	52

Salvage value of a 1000 ewe flock assumes stock remaining after normal stock sales during the year are sold at the end of the production year, hence livestock numbers reflect mortalities over 11 months

Livestock class (hd)	Weight (kg)	Price ($/kg)	Price per head ($)	Total ($)
264 maiden ewes			42.00	11 088
739 ewes	46 (l.w.)	0.50 (l.w.)	23.00	16 997
395 wether hoggets			39.00	13 825
395 ewe hoggets			42.00	13 825
19.4 rams	74 (l.w.)	0.50 (l.w.)	37.00	718
			1000 ewe flock	56 453
			Per breeding unit	**56.45**

For further information refer to the livestock enterprise budgets detailed in Alford *et al.* (2003).

Enterprise: **Prime lamb production - 2nd X lambs**

Lambing date		September-October
Weaning rate		102%
Mortality	- adult	3%
	- hogget	3%
	- lamb	5%
Ram requirement		2%
Ram cull rate		25%
Ewes	-culled for age	5.5 yrs
	- average body weight	57 kg
Lambs	- sold	6 months, March-April
Shearing date	- pre-lamb	August

Prime Lamb flock (labour hours per 1000 First-cross ewes)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
shearing								50				
crutching			25									
drenching	16		16		10					16	16	16
marking											40	
insp. & muster	17	17	17	17	17	17	17	17	17	17	17	17
lamb supervision									25	25		
fly control				15								15
classing &cull		20										
Total	33	37	58	32	27	17	17	67	42	58	73	48

Salvage value of a 1000 ewe flock assumes stock remaining after normal stock sales during the year are sold at the end of the production year, hence livestock numbers reflect mortalities over 11 months

Livestock class (hd)	Weight (kg)	Price ($/kg)	Price per head ($)	Total ($)
264 maiden ewes*			55.00	14 520
739 ewes	57 (l.w.)	0.50 (l.w.)	28.50	21 061
19.4 rams	82 (l.w.)	0.50 (l.w.)	41.00	795
			1000 ewe flock	36 376
			Per breeding unit	**36.40**

*Assumed to be sold at purchase price, see Alford *et al*. (2003).

For further information refer to the livestock enterprise budgets detailed in Alford *et al*. (2003).

Enterprise: **Merino wether flock – 19 micron**

Hoggets	- purchase	1.5 yrs
Mortality	- adult	2%
Wethers	-culled for age	5.5 yrs
	- average body weight	45 kg
Shearing date		November

Merino wether flock (labour hours per 1000 wethers)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
shearing											55	
crutching			25									
drenching	16		16		10					16	16	16
marking												
insp. & muster	12	12	12	12	12	12	12	12	12	12	12	12
fly control				15								15
classing &cull		20										
Total	28	32	68	12	22	12	12	12	12	28	83	43

Salvage value of a 1000 wether flock assumes stock remaining after normal stock sales during the year are sold at the end of the production year, hence livestock numbers reflect mortalities over 11 months

Livestock class (hd)	Weight (kg)	Price ($/kg)	Price per head ($)	Total ($)
981.5 wethers	45 (l.w.)	0.50 (l.w.)	22.50	22 084
			1000 wether flock	22 084
			Per wether	**22.08**

For further information refer to the livestock enterprise budgets detailed in Alford *et al*. (2003).

APPENDIX B

Pasture Production Assumptions

Pasture Production (t DM/ha)

	Perennial	Native	Forage Oats
January	1.28	0.97	0
February	1.42	0.87	0
March	1.60	0.81	0.50
April	1.18	0.32	0.85
May	0.69	0.11	0.50
June	0.34	0.06	0.45
July	0.30	0.06	0.45
August	0.50	0.10	0.75
September	0.87	0.48	1.35
October	1.74	0.87	1.53
November	1.60	1.06	0.67
December	0.84	1.03	0

Pasture Quality (MJ ME/kg)

	Perennial	Native	Forage Oats
January	10.0	8.0	0.0
February	9.5	8.0	0.0
March	9.0	8.0	0.0
April	8.0	8.0	9.0
May	8.0	8.0	9.0
June	7.5	7.5	8.0
July	7.5	7.5	8.0
August	7.5	7.5	8.0
September	9.0	8.0	9.0
October	10.0	10.0	8.0
November	10.7	10.0	8.0
December	10.5	9.0	0.0

Pasture carry-over assumptions

	DM as % Previous Month	ME as % Previous month
January	0.9	0.67
February	0.9	0.72
March	0.9	0.71
April	0.9	0.75
May	0.9	0.73
June	0.9	0.73
July	0.9	0.65
August	0.9	0.60
September	0.9	0.67
October	0.9	0.75
November	0.9	0.75
December	0.9	0.70

It is assumed in the model that a maximum of 50 per cent of pasture grown is available to livestock.

APPENDIX C

Description of Animal Feed Model

The energy requirements of the ruminant animal are expressed as net energy (NE) for each of the main biological functions of the animal including maintenance, growth, gestation and lactation. These net energy values are converted to metabolisable energy (ME) units by correcting for the efficiencies of utilisation of ME. This level of efficiency varies depending upon the quality of the feed available to the animal and the function for which the energy is used by the animal (McDonald, Edwards, Greenhalgh and Morgan, 2002).

In summary, the total ME requirements of the ruminant is (SCA, 1990):

$$\textbf{ME requirement} = \frac{NE_m}{k_m} + \frac{NE_g}{k_g} + \frac{NE_c}{k_c} + \frac{NE_l}{k_l}$$

Where:

NE_m is net energy for maintenance,
NE_g is net energy for growth,
NE_c is net energy for conceptus,
NE_l is net energy for lactation, and
$k_{subscript}$ refers to the corresponding efficiency factor.

[Note; k_c relating to the efficiency of ME use for conceptus growth is a gross efficiency, refer to SCA (1990)].

Australian studies have found that the United Kingdom's Ministry of Agriculture, Fisheries and Food (MAFF) (1975) equations for predicting ME requirements of sheep and cattle tend in practice, to under-estimate these requirements under Australian conditions. The Standing Committee on Agriculture (SCA) (1990) partly attributes this underestimation as being a consequence of Australia's production system characteristics such as more extensive grazing and the more variable pasture quality available to sheep and beef enterprises.

As with any modelling activity compromise between exactness and practical application to achieve a particular modelling purpose is necessary. The high degree or accuracy of predictions of models incorporating the SCA (1990) equations come at the cost of large numbers of variables data for which may not always be available.

To overcome this apparent underestimation of ME requirements, the NTLP model incorporates more recent predictive equations from MAFF (1984) and more recent refinements to this standard as described by McDonald *et al.* (2002) and SCA (1990). As well, enhancements as suggested by SCA (1990) without incorporating more complex equations were also included most notably an increased maintenance allowance to account for the animal's grazing effort. The predictive equations and associated assumptions are described below. Unless otherwise stated, equations are from McDonald *et al*. (2002)

Maintenance

ME_m for Beef Cattle

$$ME_m = \frac{0.53(W/1.08)^{0.67}}{k_m}$$

$$k_m = 0.02 * M/D + 0.5$$

Where W is liveweight (kg), and
M/D is megajoules (MJ) of ME per kg feed Dry Matter (DM).

An additional 15 per cent is applied to entire males.

ME_m for Sheep

$$MEm = \frac{0.226(W/1.08)^{0.75}}{k_m}$$

$$k_m = 0.02 * M/D + 0.5$$

An additional 15 per cent is applied to entire males.

To account for grazing activity and other maintenance requirements as discussed by SCA (1990), the ME_m figures for sheep and cattle are increased by a factor of 1.35. This additional allowance follows that described by Rickards and Passmore (1977) and similarly applied by Farquharson (1991) and is within the range of 10 to 50 per cent as determined by SCA (1990).

Growth

ME_g for Beef Cattle

$$ME_g MJ/kgLWG = \frac{(4.1 + 0.0332W - 9.0*10^{-6}W^2)/(1 - 0.1475\Delta W)}{k_g}$$

$$k_g = 0.043 * M/D$$

Where LWG is liveweight gain per day (kg).

To allow for the effect of sex on the energy contents of gains a 15 per cent correction factor is applied +15 per cent for females and – 15 per cent for males (McDonald *et al.,* 2002).

ME_g for Sheep

For Merino castrates: $ME_g MJ/kgLWG = \frac{1.53 + 0.51W}{k_g}$; (SCA,1990).

For other breed castrates: $ME_g MJ/kgLWG = \frac{4.4 + 0.35W}{k_g}$

For females: $$ME_g MJ / kgLWG = \frac{2.1 + 0.45W}{k_g}$$

For males: $$ME_g MJ / kgLWG = \frac{2.5 + 0.35W}{k_g}$$

$$k_g = 0.043 * M / D$$

Gestation

Gompertz equations are used to describe the energy gains during pregnancy (SCA, 1990).

ME_c for Beef Cattle

$$ME_c = \frac{E_{(t)} * 0.0201e^{(-0.0000576t)}}{k_c}$$

$$k_c = 0.133$$

Where E is the energy content (MJ) of the foetus and uterus;
t is the number of days from conception; and
$\log_{10}\{E_{(t)}\} = 151.665 - 151.64e^{(-0.0000576t)}$.

As for cattle, since energy cost during early and mid gestation is negligible, ME_c is only included in the last trimester for cattle.

ME_c for Sheep

$$ME_c = \frac{E_{(t)} * 0.07372e^{(-0.00643t)}}{k_c}$$

$$k_c = 0.133$$

Where E is the energy content (MJ) of the foetus and uterus;
t is the number of days from conception; and
$\log_{10}\{E_{(t)}\} = 3.322 - 4.979e^{(-0.00643t)}$.

Due to the negligible energy cost during early and mid gestation, ME_c is only included in the last two months of gestation for sheep.

Lactation

ME_l for Beef Cattle

$$ME_l = \frac{1.509 + 0.0406F}{k_l} * litres$$

$$k_l = 0.02 * M / D + 0.4$$

Where F is percentage fat in milk.

ME_l for Sheep

$$\boldsymbol{ME_l} = \frac{4.6}{\boldsymbol{k_l}} * \boldsymbol{litres}$$

$$\boldsymbol{k_l} = 0.02 * \boldsymbol{M} / \boldsymbol{D} + 0.4$$

This equation is used when milk composition is unknown.

Energy from Liveweight Loss

The energy made available to the ruminant animal by using body reserves by the catabolism of body fat and protein must also be accounted for. As in the DNRE (1999) model, it is assumed that 1 kg of body weight requires 34 MJ of ME and that 1 kg loss of liveweight provides 28MJ of ME for maintenance, pregnancy and lactation. This approximates an efficiency of use of 80 per cent as reported by SCA (1990).

Dry Matter Intake

Prediction of dry matter intake (DMI) and maximum DMI is treated in detail by SCA (1990) and simulation models such as GRAZFEED (Freer *et al*., 1997) where the potential intake of ruminants is related to the dry matter digestibility of the feed on offer, the body size of the animal and its physiological state under the assumption of abundant feed. This potential intake is modified by the relative intake of the animal which is dependent the feed's relative availability such as the height and structure of the pasture sward, and the relative indigestibility or quality of the feed being offered (Freer *et al*., 1997). However, to avoid these complexities which rely on interaction with the pasture base, a simplified method of determining maximum DMI for the various classes of livestock on a daily basis and converted to a monthly basis is used. This predictive equation was applied by Rickards and Passmore (1977) and has been subsequently used in other models such as Kingwell and Pannell (1986), where

$DMI = W^{0.78} \times (7.8 + 1.05 \times DOMD)$.

Where DOMD is Digestible Organic Matter as a percentage of total dry matter.

APPENDIX D

Land resources and livestock enterprises including minimum thresholds sub-matrix

			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17		
			PPast	NPast	Oats	SRM	SRM500	PL	PL500	MW	MW500	VL	VL100	W	W100	YC	YC100	HFS	HFS100	sign	RHS
		Units	ha	ha	ha	bu	bu x500	bu	bu x500	hd	hd x500	bu	bu x100	bu	bu x100	bu	bu x100	bu	bu x100		
	OBJ FN	$	-67.78	-25.40	-161.98	-22.48	-11239	-30.78	-15390	-19.24	-9620	-216.58	-21658	-65.57	-6557	-75.03	-7503	-81.51	-8151		
1	Land	ha	1	1	1															=	920
2	PPast	ha	1																	=	450
3	NPast	ha		1																=	440
4	Oats	ha			1															=	30
9	SRM bp	hd				1	-10000													≤	0
10	PL bp	hd						1	-10000											≤	0
11	MW bp	hd								1	-10000									≤	0
12	VL bp	hd										1	-1000							≤	0
13	W bp	hd												1	-1000					≤	0
14	YC bp	hd														1	-1000			≤	0
15	HFS bp	hd																1	-1000	≤	0

Perennial pasture feed transfers sub-matrix

			1	30	31	32	33	34	35	36	37	38	39	40	41
			PPast	PPLJan	PPLFeb	PPLMar	PPLApr	PPLMay	PPLJun	PPLJul	PPLAug	PPLSep	PPLOct	PPLNov	PPLDec
		Units	ha												
18	PP Jan	MJME	-12820	20000											
19	PP Feb	MJME	-13462		19000										
20	PP Mar	MJME	-12420			18000									
21	PP Apr	MJME	-7200				16000								
22	PP May	MJME	-3600					16000							
23	PP Jun	MJME	-2400						15000						
24	PP Jul	MJME	-2250							15000					
25	PP Aug	MJME	-3150								15000				
26	PP Sep	MJME	-7290									18000			
27	PP Oct	MJME	-13000										20000		
28	PP Nov	MJME	-17145											21400	
29	PP Dec	MJME	-16275												21000

Perennial pasture feed transfers sub-matrix (Continued)

			42	43	44	45	46	47	48	49	50	51	52	53	sign	RHS
			PPMJan	PPMFeb	PPMMar	PPMApr	PPMMay	PPMJun	PPMJul	PPMAug	PPMSep	PPMOct	PPMNov	PPMDec		
		Units														
18	PP Jan	MJME	1000											-630	≤	0
19	PP Feb	MJME	-603	1000											≤	0
20	PP Mar	MJME		-644	1000										≤	0
21	PP Apr	MJME			-635	1000									≤	0
22	PP May	MJME				-675	1000								≤	0
23	PP Jun	MJME					-653	1000							≤	0
24	PP Jul	MJME						-657	1000						≤	0
25	PP Aug	MJME							-585	1000					≤	0
26	PP Sep	MJME								-540	1000				≤	0
27	PP Oct	MJME									-605	1000			≤	0
28	PP Nov	MJME										-675	1000		≤	0
29	PP Dec	MJME											-675	1000	≤	0

Native pasture feed transfers sub-matrix

			2	54	55	56	57	58	59	60	61	62	63	64	65
				NPLJan	NPLFeb	NPLMar	NPLApr	NPLMay	NPLJun	NPLJul	NPLAug	NPLSep	NPLOct	NPLNov	NPLDec
		Units	ha												
30	NP Jan	MJME	-7920	16000											
31	NP Feb	MJME	-8000		16000										
32	NP Mar	MJME	-6507			16000									
33	NP Apr	MJME	-2560				16000								
34	NP May	MJME	-1040					16000							
35	NP Jun	MJME	-750						15000						
36	NP Jul	MJME	-750							15000					
37	NP Aug	MJME	-1500								15000				
38	NP Sep	MJME	-3867									16000			
39	NP Oct	MJME	-8700										20000		
40	NP Nov	MJME	-10633											20000	
41	NP Dec	MJME	-9240												18000

Native pasture feed transfers sub-matrix (Continued)

			66	67	68	69	70	71	72	73	74	75	76	77	sign	RHS
			NPMJan	NPMFeb	NPMMar	NPMApr	NPMMay	NPMJun	NPMJul	NPMAug	NPMSep	NPMOct	NPMNov	NPMDec		
		Units														
30	NP Jan	MJME	1000											-630	≤	0
31	NP Feb	MJME	-603	1000											≤	0
32	NP Mar	MJME		-644	1000										≤	0
33	NP Apr	MJME			-635	1000									≤	0
34	NP May	MJME				-676	1000								≤	0
35	NP Jun	MJME					-653	1000							≤	0
36	NP Jul	MJME						-657	1000						≤	0
37	NP Aug	MJME							-585	1000					≤	0
38	NP Sep	MJME								-540	1000				≤	0
39	NP Oct	MJME									-605	1000			≤	0
40	NP Nov	MJME										-675	1000		≤	0
41	NP Dec	MJME											-675	1000	≤	0

Forage oats feed transfers sub-matrix

			3	78	79	80	81	82	83	84	85	86	87	88	89
			Oats	OLJan	OLFeb	OLMar	OLApr	OLMay	OLJun	OLJul	OLAug	OLSep	OLOct	OLNov	OLDec
		Units	ha												
42	Oats Jan	MJME	0	0											
43	Oats Feb	MJME	0		0										
44	Oats Mar	MJME	0			0									
45	Oats Apr	MJME	-7620				18000								
46	Oats May	MJME	-5040					18000							
47	Oats Jun	MJME	-4400						16000						
48	Oats Jul	MJME	-4480							16000					
49	Oats Aug	MJME	-6800								16000				
50	Oats Sep	MJME	-12600									18000			
51	Oats Oct	MJME	-12560										16000		
52	Oats Nov	MJME	-5600											16000	
53	Oats Dec	MJME	0												0

Forage oats feed transfers sub-matrix (Continued)

			90	91	92	93	94	95	96	97	98	99	100	101	sign	RHS
			OMJan	OMFeb	OMMar	OMApr	OMMay	OMJun	OMJul	OMAug	OMSep	OMOct	OMNov	OMDec		
		Units														
42	Oats Jan	MJME	1000											-630	≤	0
43	Oats Feb	MJME	-603	1000											≤	0
44	Oats Mar	MJME		-644	1000										≤	0
45	Oats Apr	MJME			-635	1000									≤	0
46	Oats May	MJME				-676	1000								≤	0
47	Oats Jun	MJME					-653	1000							≤	0
48	Oats Jul	MJME						-657	1000						≤	0
49	Oats Aug	MJME							-585	1000					≤	0
50	Oats Sep	MJME								-540	1000				≤	0
51	Oats Oct	MJME									-605	1000			≤	0
52	Oats Nov	MJME										-675	1000		≤	0
53	Oats Dec	MJME											-675	1000	≤	0

Perennial pasture feed pool and DMI sub-matrix

			30	31	32	33	34	35	36	37	38	39	40	41
			NPLJan	NPLFeb	NPLMar	NPLApr	NPLMay	NPLJun	NPLJul	NPLAug	NPLSep	NPLOct	NPLNov	NPLDec
		Units												
54	FdPl Jan	MJME	-10000											
55	FdPl Feb	MJME		-9500										
56	FdPl Mar	MJME			-9000									
57	FdPl Apr	MJME				-8000								
58	FdPl May	MJME					-8000							
59	FdPl Jun	MJME						-7500						
60	FdPl Jul	MJME							-7500					
61	FdPl Aug	MJME								-7500				
62	FdPl Sep	MJME									-9000			
63	FdPl Oct	MJME										-10000		
64	FdPl Nov	MJME											-10700	
65	FdPl Dec	MJME												-10500
66	DMI Jan	t DM	-1											
67	DMI Feb	t DM		-1										
68	DMI Mar	t DM			-1									
69	DMI Apr	t DM				-1								
70	DMI May	t DM					-1							
71	DMI Jun	t DM						-1						
72	DMI Jul	t DM							-1					
73	DMI Aug	t DM								-1				
74	DMI Sep	t DM									-1			
75	DMI Oct	t DM										-1		
76	DMI Nov	t DM											-1	
77	DMI Dec	t DM												-1

Native pasture feed pool and DMI sub-matrix

			Native Pasture: Feed transfer to Livestock											
			Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
		Units												
54	FdPl Jan	MJME	-8000											
55	FdPl Feb	MJME		-8000										
56	FdPl Mar	MJME			-8000									
57	FdPl Apr	MJME				-8000								
58	FdPl May	MJME					-8000							
59	FdPl Jun	MJME						-7500						
60	FdPl Jul	MJME							-7500					
61	FdPl Aug	MJME								-7500				
62	FdPl Sep	MJME									-8000			
63	FdPl Oct	MJME										-10000		
64	FdPl Nov	MJME											-10000	
65	FdPl Dec	MJME												-9000
66	DMI Jan	t DM	-1											
67	DMI Feb	t DM		-1										
68	DMI Mar	t DM			-1									
69	DMI Apr	t DM				-1								
70	DMI May	t DM					-1							
71	DMI Jun	t DM						-1						
72	DMI Jul	t DM							-1					
73	DMI Aug	t DM								-1				
74	DMI Sep	t DM									-1			
75	DMI Oct	t DM										-1		
76	DMI Nov	t DM											-1	
77	DMI Dec	t DM												-1

Forage oats feed pool and DMI sub-matrix

			Forage Oats: Feed transfer to Livestock											
			Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
		Units												
54	FdPl Jan	MJME	0											
55	FdPl Feb	MJME		0										
56	FdPl Mar	MJME			0									
57	FdPl Apr	MJME				-9000								
58	FdPl May	MJME					-9000							
59	FdPl Jun	MJME						-8000						
60	FdPl Jul	MJME							-8000					
61	FdPl Aug	MJME								-8000				
62	FdPl Sep	MJME									-9000			
63	FdPl Oct	MJME										-8000		
64	FdPl Nov	MJME											-8000	
65	FdPl Dec	MJME												0
66	DMI Jan	t DM	-1											
67	DMI Feb	t DM		-1										
68	DMI Mar	t DM			-1									
69	DMI Apr	t DM				-1								
70	DMI May	t DM					-1							
71	DMI Jun	t DM						-1						
72	DMI Jul	t DM							-1					
73	DMI Aug	t DM								-1				
74	DMI Sep	t DM									-1			
75	DMI Oct	t DM										-1		
76	DMI Nov	t DM											-1	
77	DMI Dec	t DM												-1

Fodder conservation sub-matrix

			102	103	104	105	106	107		
			PPasthay	PPast sil	Oats hay	Oats sil	Buy hay	Sell hay	sign	RHS
		Units	ha	ha						
5	PPConsv	ha	1	1					≤	5
6	OatConsv	ha			1	1			≤	5
8	Mhay	tDM					1		≤	20
16	PHayPl	MJME	-6927		-2688		-8000	8000	≤	0
17	PSilPl	MJ ME		-11632		-12560			≤	0
27	PP Oct	MJ ME		13000					≤	0
28	PP Nov	MJ ME	17145	17145					≤	0
29	PP Dec	MJ ME	16275						≤	0
51	Oats Oct	MJ ME				12560			≤	0
52	Oats Nov	MJ ME			5600	5600			≤	0

Feed hay sub-matrix

			102 Ppast hay	104 Oats hay	106 Buy hay	107 Sell hay	108 FHJan	109 FHFeb	110 FHMar	111 FHApr	112 FHMay	113 FHJun	114 FHJul	115 FHAug	116 FHSep	117 FHOct	118 FHNov	119 FHDec	sign	RHS
		Units					t DM	t DM	t DM	t DM	t DM	t DM	t DM	t DM	t DM	t DM	t DM	t DM		
16	PHayPl	MJME	-6927	-2688	-8000	8000	9412	9412	9412	9412	9412	9412	9412	9412	9412	9412	9412	9412		
28	PP Nov	MJME	17145																	
29	PP Dec	MJME	16275																	
52	Oats Nov	MJME		5600																
54	FdPl Jan	MJME					-8500												≤	0
55	FdPl Feb	MJME						-8500											≤	0
56	FdPl Mar	MJME							-8500										≤	0
57	FdPl Apr	MJME								-8500									≤	0
58	FdPl May	MJME									-8500								≤	0
59	FdPl Jun	MJME										-8500							≤	0
60	FdPl Jul	MJME											-8500						≤	0
61	FdPl Aug	MJME												-8500					≤	0
62	FdPl Sep	MJME													-8500				≤	0
63	FdPl Oct	MJME														-8500			≤	0
64	FdPl Nov	MJME															-8500		≤	0
65	FdPl Dec	MJME																-8500	≤	0
66	DMI Jan	t DM					-1												≥	0
67	DMI Feb	t DM						-1											≥	0
68	DMI Mar	t DM							-1										≥	0
69	DMI Apr	t DM								-1									≥	0
70	DMI May	t DM									-1								≥	0
71	DMI Jun	t DM										-1							≥	0
72	DMI Jul	t DM											-1						≥	0
73	DMI Aug	t DM												-1					≥	0
74	DMI Sep	t DM													-1				≥	0
75	DMI Oct	t DM														-1			≥	0
76	DMI Nov	t DM															-1		≥	0
77	DMI Dec	t DM																-1	≥	0

Feed Silage Sub-matrix

		Units	120 FS Jan t DM	121 FS Feb t DM	122 FS Mar t DM	123 FS Apr t DM	124 FS May t DM	125 FS Jun t DM	126 FS Jul t DM	127 FS Aug t DM	128 FS Sep t DM	129 FS Oct t DM	130 FS Nov t DM	131 FS Dec t DM
17	PSil Pl	MJME	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000
54	FdPl Jan	MJME	-8500											
55	FdPl Feb	MJME		-8500										
56	FdPl Mar	MJME			-8500									
57	FdPl Apr	MJME				-8500								
58	FdPl May	MJME					-8500							
59	FdPl Jun	MJME						-8500						
60	FdPl Jul	MJME							-8500					
61	FdPl Aug	MJME								-8500				
62	FdPl Sep	MJME									-8500			
63	FdPl Oct	MJME										-8500		
64	FdPl Nov	MJME											-8500	
65	FdPl Dec	MJME												-8500
66	DMI Jan	t DM	-1											
67	DMI Feb	t DM		-1										
68	DMI Mar	t DM			-1									
69	DMI Apr	t DM				-1								
70	DMI May	t DM					-1							
71	DMI Jun	t DM						-1						
72	DMI Jul	t DM							-1					
73	DMI Aug	t DM								-1				
74	DMI Sep	t DM									-1			
75	DMI Oct	t DM										-1		
76	DMI Nov	t DM											-1	
77	DMI Dec	t DM												-1

Buy/Feed Grain Sub-matrix

			132	133	134	135	136	137	138	139	140	141	142	143		
			FG Jan	FG Feb	FG Mar	FG Apr	FG May	FG Jun	FG Jul	FG Aug	FG Sep	FG Oct	FG Nov	FG Dec	Sign	RHS
		Units	t DM	t DM	t DM	t DM	t DM	t DM	t DM	t DM	t DM	t DM	t DM	t DM		
	OBJ FN	$	-170.45	-170.45	-170.45	-170.45	-170.45	-170.45	-170.45	-170.45	-170.45	-170.45	-170.45	-170.45		
7	Mgrain	t DM	1	1	1	1	1	1	1	1	1	1	1	1	≤	10
54	FdPl Jan	MJME	-10625												≤	0
55	FdPl Feb	MJME		-10625											≤	0
56	FdPl Mar	MJME			-10625										≤	0
57	FdPl Apr	MJME				-10625									≤	0
58	FdPl May	MJME					-10625								≤	0
59	FdPl Jun	MJME						-10625							≤	0
60	FdPl Jul	MJME							-10625						≤	0
61	FdPl Aug	MJME								-10625					≤	0
62	FdPl Sep	MJME									-10625				≤	0
63	FdPl Oct	MJME										-10625			≤	0
64	FdPl Nov	MJME											-10625		≤	0
65	FdPl Dec	MJME												-10625	≤	0
66	DMI Jan	t DM	-1												≥	0
67	DMI Feb	t DM		-1											≥	0
68	DMI Mar	t DM			-1										≥	0
69	DMI Apr	t DM				-1									≥	0
70	DMI May	t DM					-1								≥	0
71	DMI Jun	t DM						-1							≥	0
72	DMI Jul	t DM							-1						≥	0
73	DMI Aug	t DM								-1					≥	0
74	DMI Sep	t DM									-1				≥	0
75	DMI Oct	t DM										-1			≥	0
76	DMI Nov	t DM											-1		≥	0
77	DMI Dec	t DM												-1	≥	0

Animal feed requirements and maximum dry matter intake sub-matrix

			4	5	6	7	8	9	10	11	12	13	14	15	16	17		
			SRM	SRM500	PL	PL500	MW	MW500	Veal	Veal100	Wean	Wean100	YC	YC100	HFS	HFS100	sign	RHS
		units	bu	bu x500	bu	bu x500	hd	hd x500	bu	bu x100	bu	bu x100	bu	bu x100	bu	bu x100		
54	FdPl Jan	MJME	658.7	329335.2	769.9	384971.2	259.8	129920.1	4407.9	440794.5	5057.3	505730.4	6460.3	646028.7	5638.7	563871.6	≤	0
55	FdPl Feb	MJME	618.6	309318.3	771.7	385873.9	224.3	112125	4274.8	427483.3	4812.4	481239.8	5907.6	590757.3	4897.3	489731.7	≤	0
56	FdPl Mar	MJME	520.3	260135.1	873.2	436590.5	245.4	122697.8	5596.4	559642.6	5481.3	548125.9	6030.5	603045.0	4949.2	494922.7	≤	0
57	FdPl Apr	MJME	493.0	246499.8	477.5	238728.2	241.2	120581.7	4643.4	464336.6	5522.3	552229.7	5386.0	538596.3	5083.1	508306.9	≤	0
58	FdPl May	MJME	491.5	245767.7	381.6	190798.4	254.3	127129.7	3380.0	338002.5	4949.2	494922.7	5127.3	512731.7	4917.4	491744.2	≤	0
59	FdPl Jun	MJME	428.8	214421.9	270.8	135413.3	247.5	123725.6	3618.9	361886.0	4082.1	408208.3	4794.8	479479.8	4364.8	436484.7	≤	0
60	FdPl Jul	MJME	467.0	233507.4	296.6	148305.5	257.2	128580.7	3947.4	394737.8	4214.2	421418.2	5233.1	523307.8	4539.9	453993.4	≤	0
61	FdPl Aug	MJME	545.0	272491.5	364.9	182455.6	260.6	130302.3	3903.6	390358.3	4379.5	437951.5	5777.9	577788.2	4769.4	476942.1	≤	0
62	FdPl Sep	MJME	808.8	404412.5	732.3	366147.0	251.8	125879.7	4019.6	401960.0	4615.9	461592.2	6067.3	606728.0	5050.0	505004.0	≤	0
63	FdPl Oct	MJME	820.5	410255.8	737.2	368602.5	263.7	131846.7	4220.8	422083.9	4951.3	495131.9	6354.1	635410.7	5348.8	534882.8	≤	0
64	FdPl Nov	MJME	702.9	351455.2	604.1	302071.2	254.7	127370.9	3952.3	395226.7	4701.6	470158.1	6003.4	600345.0	5059.3	505926.9	≤	0
65	FdPl Dec	MJME	652.6	326283.9	681.9	340958.9	262.8	131386.5	4174.5	417446.3	4746.7	474668.6	6131.6	613158.4	5188.5	518847.9	≤	0
66	DMI Jan	t DM	0.087	43.710	0.084	42.098	0.039	19.734	0.588	58.776	0.605	60.454	0.741	74.119	0.679	67.927	≥	0
67	DMI Feb	t DM	0.082	40.757	0.080	39.754	0.036	17.891	0.544	54.368	0.551	55.147	0.674	67.411	0.579	57.938	≥	0
68	DMI Mar	t DM	0.072	36.197	0.105	52.677	0.041	20.706	0.669	66.888	0.645	64.489	0.782	78.243	0.629	62.852	≥	0
69	DMI Apr	t DM	0.065	32.458	0.070	35.181	0.040	19.803	0.523	52.348	0.622	62.199	0.701	70.131	0.617	61.659	≥	0
70	DMI May	t DM	0.069	34.340	0.064	32.138	0.041	20.512	0.390	39.047	0.546	54.623	0.606	60.574	0.558	55.788	≥	0
71	DMI Jun	t DM	0.067	33.733	0.053	26.443	0.040	19.878	0.382	38.239	0.428	42.770	0.531	53.072	0.459	45.947	≥	0
72	DMI Jul	t DM	0.069	34.278	0.051	25.350	0.041	20.255	0.466	46.603	0.442	44.211	0.552	55.238	0.479	47.898	≥	0
73	DMI Aug	t DM	0.067	33.737	0.049	24.696	0.040	20.078	0.544	54.446	0.496	49.609	0.610	60.995	0.551	55.055	≥	0
74	DMI Sep	t DM	0.073	36.696	0.057	28.724	0.039	19.588	0.542	54.158	0.557	55.699	0.662	66.226	0.617	61.745	≥	0
75	DMI Oct	t DM	0.081	40.734	0.066	33.083	0.040	20.169	0.569	56.936	0.598	59.823	0.704	70.385	0.655	65.479	≥	0
76	DMI Nov	t DM	0.073	36.356	0.057	28.416	0.038	18.768	0.546	54.629	0.570	57.017	0.677	67.725	0.627	62.681	≥	0
77	DMI Dec	t DM	0.080	40.007	0.074	36.970	0.037	18.697	0.557	55.698	0.584	58.410	0.699	69.857	0.643	64.269	≥	0

Labour Sub-matrix

			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
			PPast	NPast	Oats	SRM	SRM500	PL	PL500	MW	MW500	Veal	Veal100	Wean	Wean100	YC	YC100	HFS	HFS100
		Units	ha	ha	ha	bu	bu x500	bu	bu x500	hd	hd x500	bu	bu x100	bu	bu x100	bu	bu x100	bu	bu x100
	OBJ FNC	$	-67.78	-161.98	-25.40	-22.48	-11239	-30.78	-15390	-19.24	-9620	-216.58	-21658	-65.57	-6557	-75.03	-7503	-81.51	-8151
78	LbJan	Hrs				0.037	18.5	0.033	16.5	0.028	14.0	0.20	20.0	0.2	20.0	0.20	20.0	0.45	45.0
79	LbFeb	Hrs			2.5	0.037	18.5	0.037	18.5	0.032	16.0	0.20	20.0	0.2	20.0	0.20	20.0	0.20	20.0
80	LbMar	Hrs	0.092	0.014		0.062	31.0	0.058	29.0	0.053	26.5	0.65	65.0	0.52	52.0	0.40	40.0	0.65	65.0
81	LbApr	Hrs	0.092			0.032	16.0	0.032	16.0	0.027	13.5	0.30	30.0	0.4	40.0	0.20	20.0	0.30	30.0
82	LbMay	Hrs				0.027	13.5	0.027	13.5	0.022	11.0	0.25	25.0	0.28	28.0	0.20	20.0	0.25	25.0
83	LbJun	Hrs				0.017	8.5	0.017	8.5	0.012	6.0	0.30	30.0	0.3	30.0	0.55	55.0	0.30	30.0
84	LbJul	Hrs				0.017	8.5	0.017	8.5	0.012	6.0	0.30	30.0	0.3	30.0	0.34	34.0	0.30	30.0
85	LbAug	Hrs				0.077	38.5	0.067	33.5	0.012	6.0	0.50	50.0	0.5	50.0	0.54	54.0	0.50	50.0
86	LbSep	Hrs				0.042	21.0	0.042	21.0	0.012	6.0	0.30	30.0	0.3	30.0	0.42	42.0	0.30	30.0
87	LbOct	Hrs				0.062	31.0	0.058	29.0	0.028	14.0	0.20	20.0	0.45	45.0	0.20	20.0	0.35	35.0
88	LbNov	Hrs				0.077	38.5	0.073	36.5	0.083	41.5	0.20	20.0	0.2	20.0	0.20	20.0	0.20	20.0
89	LbDec	Hrs				0.052	26.0	0.048	24.0	0.043	21.5	0.70	70.0	0.45	45.0	0.65	65.0	0.30	30.0

Labour Sub-matrix (Continued)

			18	19	20	21	22	23	24	25	26	27	28	29		
			CLbJan	CLbFeb	CLbMar	CLbApr	CLbMay	CLbJun	CLbJul	CLbAug	CLbSep	CLbOct	CLbNov	CLbDec	sign	RHS
		Units	Hrs	Hrs	Hrs	Hrs	Hrs	Hrs	Hrs	Hrs	Hrs	Hrs	Hrs	Hrs		
	OBJ FNC	$	-20.00	-20.00	-20.00	-20.00	-20.00	-20.00	-20.00	-20.00	-20.00	-20.00	-20.00	-20.00		
78	LbJan	Hrs	-1												≤	250
79	LbFeb	Hrs		-1											≤	250
80	LbMar	Hrs			-1										≤	250
81	LbApr	Hrs				-1									≤	250
82	LbMay	Hrs					-1								≤	250
83	LbJun	Hrs						-1							≤	250
84	LbJul	Hrs							-1						≤	250
85	LbAug	Hrs								-1					≤	250
86	LbSep	Hrs									-1				≤	250
87	LbOct	Hrs										-1			≤	250
88	LbNov	Hrs											-1		≤	250
89	LbDec	Hrs												-1	≤	250

Livestock commodity outputs sub-matrix

			4	5	6	7	8	9	10	11	12	13	14	15	16	17
			SRM	SRM500	PL	PL500	MW	MW500	VL	VL100	W	W100	YC	YC100	HFS	HFS100
	units		bu	bu x500	bu	bu x500	hd	hd x500	bu	bu x100	bu	bu x100	bu	bu x100	bu	bu x100
	OBJ FN	$	-22.48	-11239	-30.78	-15390	-19.24	-9620	-216.58	-21658	-65.57	-6557	-75.03	-7503	-81.51	-8151
90	SRMW	hd	-4.56	-2282												
91	XBW	hd			-2.94	-1472										
92	MWW	hd					-3.00	-1500								
93	PLL	hd			-1.06	-531										
94	SRMEcfa	hd	-0.02	-11												
95	XBEcfa	hd			-0.02	-116										
96	MW	hd	-0.39	-194												
97	MEw	hd	-0.12	-61												
98	MWcfa	hd					-0.24	-119								
99	RMcfa	hd	-.005	-2.5	-.005	-2.5										
100	VLst	hd							-0.42	-41.6						
101	VLhe	hd							-0.42	-41.6						
102	Wst	hd									-0.41	-40.6				
103	Whe	hd									-0.15	-15.4				
104	Wcull	hd									-0.04	-4.3				
105	YCst	hd											-0.41	-40.5		
106	YChe	hd											-0.14	-13.9		
107	HFSst	hd													-0.41	-40.7
108	HFShe	hd													-0.18	-18.5
109	Cullhe	hd											-0.04	-3.8	-0.03	-2.9
110	VCowcfa	hd									-0.18	-17.7	-0.21	-21.0	-0.18	-18.0
111	Cowcfa	hd							-0.15	-15.1						
112	Bullcfa	hd							-0.01	-0.9	-0.01	-1.0	-0.01	-1.0	-0.01	-1.0

Livestock commodity outputs sub-matrix - continued

		144	145	146	147	148	149	150	151	152	153	154	155	156	157
		SSRMW	SXBW	SMWW	SPLL	SSRMEcfa	SXBEcfa	SMW	SMEw	SMWcfa	SRMcfa	SVLst	SVLhe	SWst	SWhe
		kg	kg	kg	hd	hd	hd	hd	hd	hd	hd	hd	hd	hd	hd
	OBJ FN	11.17	5.66	11.17	48.00	23.09	28.50	39.00	42.33	22.50	37.00	531.25	459.66	449.23	368.17
90	SRMW	1													
91	XBW		1												
92	MWW			1											
93	PLL				1										
94	SRMEcfa					1									
95	XBEcfa						1								
96	MW							1							
97	MEw								1						
98	MWcfa									1					
99	RMcfa										1				
100	VLst											1			
101	VLhe												1		
102	Wst													1	
103	Whe														1
104	Wcull														
105	YCst														
106	YChe														
107	HFSst														
108	HFShe														
109	Cullhe														
110	VCowcfa														
111	Cowcfa														
112	Bullcfa														

Livestock commodity outputs sub-matrix - continued

		158 SWcull	159 SYCst	160 SYChe	161 SHFSst	162 SHFShe	163 SCullhe	164 SVCowcfa	165 SCowcfa	166 SBullcfa	sign	RHS
		hd	hd	hd	hd	hd	hd	hd	hd	hd		
	OBJ FN	540.67	713.67	594.72	760.75	321.07	544.36	638.98	583.68	1197.00		
90	SRMW										=	0
91	XBW										=	0
92	MWW										=	0
93	PLL										=	0
94	SRMEcfa										=	0
95	XBEcfa										=	0
96	MW										=	0
97	MEw										=	0
98	MWcfa										=	0
99	RMcfa										=	0
100	VLst										=	0
101	VLhe										=	0
102	Wst										=	0
103	Whe										=	0
104	Wcull	1									=	0
105	YCst		1								=	0
106	YChe			1							=	0
107	HFSst				1						=	0
108	HFShe					1					=	0
109	Cullhe						1				=	0
110	VCowcfa							1			=	0
111	Cowcfa								1		=	0
112	Bullcfa									1	=	0

APPENDIX E

Activities

1	PPast	Perennial pasture (ha)
2	NPast	Native pasture (ha)
3	Oats	Forage oats (ha)
4	SRM	Self-replacing Merino enterprise (bu)
5	SRM500	Minimum self-replacing Merino flock enterprise (500 bu)
6	PL	Prime lamb enterprise (bu)
7	PL500	Minimum Prime lamb flock enterprise (500 bu)
8	MW	Merino wether enterprise (hd)
9	MW500	Minimum merino wether flock enterprise (500 hd)
10	VL	Cross-bred vealer enterprise (bu)
11	VL100	Minimum cross-bred vealer herd enterprise (100 bu)
12	W	Store weaner enterprise (bu)
13	W100	Minimum store weaner herd enterprise (100 bu)
14	YC	Young cattle enterprise (bu)
15	YC100	Minimum Young cattle herd enterprise (100 bu)
16	HFS	Heavy feeder steer enterprise (bu)
17	HFS100	Minimum Heavy feeder steer herd enterprise (100 bu)
18	CLb Jan	January hire casual labour (hrs)
19	CLb Feb	February hire casual labour (hrs)
20	CLb Mar	March hire casual labour (hrs)
21	CLb Apr	April hire casual labour (hrs)
22	CLb May	May hire casual labour (hrs)
23	CLb Jun	June hire casual labour (hrs)
24	CLb Jul	July hire casual labour (hrs)
25	CLb Aug	August hire casual labour (hrs)
26	CLb Sep	September hire casual labour (hrs)
27	CLb Oct	October hire casual labour (hrs)
28	CLb Nov	November hire casual labour (hrs)
29	CLb Dec	December hire casual labour (hrs)
30	NPL Jan	January perennial pasture transfer to livestock (tDM)
31	NPL Feb	February perennial pasture transfer to livestock (tDM)
32	NPL Mar	March perennial pasture transfer to livestock (tDM)
33	NPL Apr	April perennial pasture transfer to livestock (tDM)
34	NPL May	May perennial pasture transfer to livestock (tDM)
35	NPL Jun	June perennial pasture transfer to livestock (tDM)
36	NPL Jul	July perennial pasture transfer to livestock (tDM)
37	NPL Aug	August perennial pasture transfer to livestock (tDM)
38	NPL Sep	September perennial pasture transfer to livestock (tDM)
39	NPL Oct	October perennial pasture transfer to livestock (tDM)
40	NPL Nov	November perennial pasture transfer to livestock (tDM)
41	NPL Dec	December perennial pasture transfer to livestock (tDM)
42	PPM Jan	January perennial pasture transfer to next month
43	PPM Feb	February perennial pasture transfer to next month
44	PPM Mar	March perennial pasture transfer to next month
45	PPM Apr	April perennial pasture transfer to next month
46	PPM May	May perennial pasture transfer to next month
47	PPM Jun	June perennial pasture transfer to next month
48	PPM Jul	July perennial pasture transfer to next month
49	PPM Aug	August perennial pasture transfer to next month
50	PPM Sep	September perennial pasture transfer to next month
51	PPM Oct	October perennial pasture transfer to next month
52	PPM Nov	November perennial pasture transfer to next month
53	PPM Dec	December perennial pasture transfer to next month
54	NPL Jan	January native pasture transfer to livestock (tDM)
55	NPL Feb	February native pasture transfer to livestock (tDM)

56	NPL Mar	March native pasture transfer to livestock (tDM)
57	NPL Apr	April native pasture transfer to livestock (tDM)
58	NPL May	May native pasture transfer to livestock (tDM)
59	NPL Jun	June native pasture transfer to livestock (tDM)
60	NPL Jul	July native pasture transfer to livestock (tDM)
61	NPL Aug	August native pasture transfer to livestock (tDM)
62	NPL Sep	September native pasture transfer to livestock (tDM)
63	NPL Oct	October native pasture transfer to livestock (tDM)
64	NPL Nov	November native pasture transfer to livestock (tDM)
65	NPL Dec	December native pasture transfer to livestock (tDM)
66	NPM Jan	January native pasture transfer to next month
67	NPM Feb	February native pasture transfer to next month
68	NPM Mar	March native pasture transfer to next month
69	NPM Apr	April native pasture transfer to next month
70	NPM May	May native pasture transfer to next month
71	NPM Jun	June native pasture transfer to next month
72	NPM Jul	July native pasture transfer to next month
73	NPM Aug	August native pasture transfer to next month
74	NPM Sep	September native pasture transfer to next month
75	NPM Oct	October native pasture transfer to next month
76	NPM Nov	November native pasture transfer to next month
77	NPM Dec	December native pasture transfer to next month
78	OL Jan	January forage oats transfer to livestock (tDM)
79	OL Feb	February forage oats transfer to livestock (tDM)
80	OL Mar	March forage oats transfer to livestock (tDM)
81	OL Apr	April forage oats transfer to livestock (tDM)
82	OL May	May forage oats transfer to livestock (tDM)
83	OL Jun	June forage oats transfer to livestock (tDM)
84	OL Jul	July forage oats transfer to livestock (tDM)
85	OL Aug	August forage oats transfer to livestock (tDM)
86	OL Sep	September forage oats transfer to livestock (tDM)
87	OL Oct	October forage oats transfer to livestock (tDM)
88	OL Nov	November forage oats transfer to livestock (tDM)
89	OL Dec	December forage oats transfer to livestock (tDM)
90	OM Jan	January forage oats transfer to next month
91	OM Feb	February forage oats transfer to next month
92	OM Mar	March forage oats transfer to next month
93	OM Apr	April forage oats transfer to next month
94	OM May	May forage oats transfer to next month
95	OM Jun	June forage oats transfer to next month
96	OM Jul	July forage oats transfer to next month
97	OM Aug	August forage oats transfer to next month
98	OM Sep	September forage oats transfer to next month
99	OM Oct	October forage oats transfer to next month
100	OM Nov	November forage oats transfer to next month
101	OM Dec	December forage oats transfer to next month
102	PPast hay	Make hay from perennial pasture (ha)
103	PPast sil	Make silage from perennial pasture (ha)
104	Oats hay	Make hay from forage oats (ha)
105	Oats sil	Make silage from forage oats (ha)
106	Buy hay	Purchase hay (tDM)
107	Sell hay	Sell hay (tDM)
108	FH Jan	January feed hay (tDM)
109	FH Feb	February feed hay (tDM)
110	FH Mar	March feed hay (tDM)
111	FH Apr	April feed hay (tDM)
112	FH May	May feed hay (tDM)
113	FH Jun	June feed hay (tDM)
114	FH Jul	July feed hay (tDM)
115	FH Aug	August feed hay (tDM)

116	FH Sep	September feed hay (tDM)
117	FH Oct	October feed hay (tDM)
118	FH Nov	November feed hay (tDM)
119	FH Dec	December feed hay (tDM)
120	FS Jan	January feed silage (tDM)
121	FS Feb	February feed silage (tDM)
122	FS Mar	March feed silage (tDM)
123	FS Apr	April feed silage (tDM)
124	FS May	May feed silage (tDM)
125	FS Jun	June feed silage (tDM)
126	FS Jul	July feed silage (tDM)
127	FS Aug	August feed silage (tDM)
128	FS Sep	September feed silage (tDM)
129	FS Oct	October feed silage (tDM)
130	FS Nov	November feed silage (tDM)
131	FS Dec	December feed silage (tDM)
132	FG Jan	January feed purchased grain (tDM)
133	FG Feb	February feed purchased grain (tDM)
134	FG Mar	March feed purchased grain (tDM)
135	FG Apr	April feed purchased grain (tDM)
136	FG May	May feed purchased grain (tDM)
137	FG Jun	June feed purchased grain (tDM)
138	FG Jul	July feed purchased grain (tDM)
139	FG Aug	August feed purchased grain (tDM)
140	FG Sep	September feed purchased grain (tDM)
141	FG Oct	October feed purchased grain (tDM)
142	FG Nov	November feed purchased grain (tDM)
143	FG Dec	December feed purchased grain (tDM)
144	SSRMW	Sell self-replacing merino enterprise wool (kg clean)
145	SXBW	Sell cross-bred wool (kg clean)
146	SMWW	Sell Merino wether enterprise wool (kg clean)
147	SPLL	Sell Prime lambs (hd)
148	SSRMEcfa	Sell cfa Merino ewes (hd)
149	SXBEcfa	Sell cfa cross-bred ewes (hd)
150	SMW	Sell Merino wether hoggets (hd)
151	SMEw	Sell Merino surplus ewe hoggets (hd)
152	SMWcfa	Sell cfa merino wethers (hd)
153	SRcfa	Sell cfa rams (hd)
154	SVLst	Sell Vealer enterprise steers (hd)
155	SVLhe	Sell Vealer enterprise heifers (hd)
156	SWst	Sell Weaner enterprise steers (hd)
157	SWhe	Sell Weaner enterprise surplus heifers (hd)
158	SWcull	Sell Weaner enterprise cull heifers (hd)
159	SYCst	Sell Young cattle enterprise steers (hd)
160	SYChe	Sell Young cattle enterprise surplus heifers (hd)
161	SHFSst	Sell Heavy feeder steer enterprise steers (hd)
162	SHFShe	Sell Heavy feeder steer enterprise surplus heifers (hd)
163	SCullhe	Sell Cull heifers (hd)
164	SVCowcfa	Sell cfa cross-bred cows (hd)
165	SCowcfa	Sell cfa cows (hd)
166	SBullcfa	Sell cfa bulls (hd)

Constraints

	OBJ FN	Objective function ($)
1	Land	Total land area (ha)
2	PPast	Total perennial pasture area (ha)
3	NPast	Total native pasture area (ha)
4	Oats	Total forage oats area (ha)
5	PPConsv	Area available for perennial pasture hay/silage (ha)
6	OatConsv	Area available for forage oats hay/silage (ha)
7	Mgrain	Maximum amount of supplementary grain (tDM)
8	Max hay	Maximum amount of purchased hay (tDM)
9	SRM bp	Self-replacing Merino enterprise binary permission
10	PL bp	Prime lamb enterprise binary permission
11	MW bp	Merino wether enterprise binary permission
12	VL bp	Cross-bred vealer enterprise binary permission
13	W bp	Store weaner enterprise binary permission
14	YC bp	Young cattle enterprise binary permission
15	HFS bp	Heavy feeder steer enterprise binary permission
16	PHayPl	Pasture hay pool (MJ ME)
17	PSilPl	Pasture silage pool (MJ ME)
18	PP Jan	January perennial pasture energy transfers (MJ ME)
19	PP Feb	February perennial pasture energy transfers (MJ ME)
20	PP Mar	March perennial pasture energy transfers (MJ ME)
21	PP Apr	April perennial pasture energy transfers (MJ ME)
22	PP May	May perennial pasture energy transfers (MJ ME)
23	PP Jun	June perennial pasture energy transfers (MJ ME)
24	PP Jul	July perennial pasture energy transfers (MJ ME)
25	PP Aug	August perennial pasture energy transfers (MJ ME)
26	PP Sep	September perennial pasture energy transfers (MJ ME)
27	PP Oct	October perennial pasture energy transfers (MJ ME)
28	PP Nov	November perennial pasture energy transfers (MJ ME)
29	PP Dec	December perennial pasture energy transfers (MJ ME)
30	NP Jan	January native pasture energy transfers (MJ ME)
31	NP Feb	February native pasture energy transfers (MJ ME)
32	NP Mar	March native pasture energy transfers (MJ ME)
33	NP Apr	April native pasture energy transfers (MJ ME)
34	NP May	May native pasture energy transfers (MJ ME)
35	NP Jun	June native pasture energy transfers (MJ ME)
36	NP Jul	July native pasture energy transfers (MJ ME)
37	NP Aug	August native pasture energy transfers (MJ ME)
38	NP Sep	September native pasture energy transfers (MJ ME)
39	NP Oct	October native pasture energy transfers (MJ ME)
40	NP Nov	November native pasture energy transfers (MJ ME)
41	NP Dec	December native pasture energy transfers (MJ ME)
42	Oats Jan	January forage oats energy transfers (MJ ME)
43	Oats Feb	February forage oats energy transfers (MJ ME)
44	Oats Mar	March forage oats energy transfers (MJ ME)
45	Oats Apr	April forage oats energy transfers (MJ ME)
46	Oats May	May forage oats energy transfers (MJ ME)
47	Oats Jun	June forage oats energy transfers (MJ ME)
48	Oats Jul	July forage oats energy transfers (MJ ME)
49	Oats Aug	August forage oats energy transfers (MJ ME)
50	Oats Sep	September forage oats energy transfers (MJ ME)
51	Oats Oct	October forage oats energy transfers (MJ ME)
52	Oats Nov	November forage oats energy transfers (MJ ME)
53	Oats Dec	December forage oats energy transfers (MJ ME)
54	FdPl Jan	January feed pool constraint (MJ ME)
55	FdPl Feb	February feed pool constraint (MJ ME)
56	FdPl Mar	March feed pool constraint (MJ ME)
57	FdPl Apr	April feed pool constraint (MJ ME)

58	FdPl May	May feed pool constraint (MJ ME)
59	FdPl Jun	June feed pool constraint (MJ ME)
60	FdPl Jul	July feed pool constraint (MJ ME)
61	FdPl Aug	August feed pool constraint (MJ ME)
62	FdPl Sep	September feed pool constraint (MJ ME)
63	FdPl Oct	October feed pool constraint (MJ ME)
64	FdPl Nov	November feed pool constraint (MJ ME)
65	FdPl Dec	December feed pool constraint (MJ ME)
66	DMI Jan	January feed dry matter intake capacity of livestock (tDM)
67	DMI Feb	February feed dry matter intake capacity of livestock (tDM)
68	DMI Mar	March feed dry matter intake capacity of livestock (tDM)
69	DMI Apr	April feed dry matter intake capacity of livestock (tDM)
70	DMI May	May feed dry matter intake capacity of livestock (tDM)
71	DMI Jun	June feed dry matter intake capacity of livestock (tDM)
72	DMI Jul	July feed dry matter intake capacity of livestock (tDM)
73	DMI Aug	August feed dry matter intake capacity of livestock (tDM)
74	DMI Sep	September feed dry matter intake capacity of livestock (tDM)
75	DMI Oct	October feed dry matter intake capacity of livestock (tDM)
76	DMI Nov	November feed dry matter intake capacity of livestock (tDM)
77	DMI Dec	December feed dry matter intake capacity of livestock (tDM)
78	Lb Jan	January labour constraint (hrs)
79	Lb Feb	February labour constraint (hrs)
80	Lb Mar	March labour constraint (hrs)
81	Lb Apr	April labour constraint (hrs)
82	Lb May	May labour constraint (hrs)
83	Lb Jun	June labour constraint (hrs)
84	Lb Jul	July labour constraint (hrs)
85	Lb Aug	August labour constraint (hrs)
86	Lb Sep	September labour constraint (hrs)
87	Lb Oct	October labour constraint (hrs)
88	Lb Nov	November labour constraint (hrs)
89	Lb Dec	December labour constraint (hrs)
90	SRMW	Self-replacing Merino enterprise wool (kg clean)
91	XBW	Cross-bred wool (kg clean)
92	MWW	Merino wether enterprise wool (kg clean)
93	PLL	Prime lambs (hd)
94	SRMEcfa	cfa Merino ewes (hd)
95	XBEcfa	cfa cross-bred ewes (hd)
96	MW	Merino wether hoggets (hd)
97	MEw	Merino surplus ewe hoggets (hd)
98	MWcfa	cfa merino wethers (hd)
99	Rcfa	cfa rams (hd)
100	VLst	Vealer enterprise steers (hd)
101	VLhe	Vealer enterprise heifers (hd)
102	Wst	Weaner enterprise steers (hd)
103	Whe	Weaner enterprise surplus heifers (hd)
104	WCull	Weaner enterprise cull heifers (hd)
105	YCst	Young cattle enterprise steers (hd)
106	YChe	Young cattle enterprise surplus heifers (hd)
107	HFGst	Heavy feeder steer enterprise steers (hd)
108	HFGhe	Heavy feeder steer enterprise surplus heifers (hd)
109	Cull he	Cull heifers (hd)
110	VCowcfa	cfa cross-bred cows (hd)
111	Cowcfa	cfa cows (hd)
112	Bullcfa	cfa bulls (hd)

APPENDIX F

Additional Sub-matrices for Multi-period Model

Sub-matrix for the NFE Heavy Feeder Steer enterprise

Unit		N Cow2 hd	N Cow3 hd	N Cow4 hd	N Cow5 hd	N Cow6 hd	N Cow7 hd	N Cow8 hd	N Cow9 hd	N cfa cow hd	N cull cows hd	N cull heifers hd	N bull hd	N Hc hd	N Bc hd	N Hy hd	N Sty hd	N Ret Hc hd	N Sell Hc hd	N Sell st hd	N cfa bull hd	sign	RHS
cull cows	hd	-0.12	-0.12	-0.12	-0.12	-0.12	-0.12	-0.12			1											=	0
Cull H	hd											1				-0.175						=	0
Cow - cfa	hd								-0.98	1												=	0
H- Cow 2	hd	1														-0.795						=	0
Cow 2 - 3	hd	-0.86	1																			=	0
Cow 3 -4	hd		-0.86	1																		=	0
Cow 4 – 5	hd			-0.86	1																	=	0
Cow 5 – 6	hd				-0.86	1																=	0
Cow 6 – 7	hd					-0.86	1															=	0
Cow 7 – 8	hd						-0.86	1														=	0
Cow 8 – 9	hd							-0.86	1													=	0
Hc – Hy	hd															1		-0.987				=	0
Bc – Sty	hd														-0.95		1					=	0
Hc	hd	-0.43	-0.43	-0.43	-0.43	-0.43	-0.43	-0.43	-0.43					1								=	0
Bc	hd	-0.43	-0.43	-0.43	-0.43	-0.43	-0.43	-0.43	-0.43						1							=	0
H sales	hd													-0.96				1	1			=	0
St sales	hd																-0.985			1		=	0
cfa bulls	hd												-0.32								1	=	0
Join rate	hd	-0.03	-0.03	-0.03	-0.03	-0.03	-0.03	-0.03					1					-0.03				=	0

Note: The HFS enterprise has a minimum herd size of 30 cows to test the adoption of NFE bulls. Bulls are run at a rate of 3% therefore approximately 30 cows are required for each bull.

Inter-year transfer ties for livestock enterprises sub-matrix (abbreviated)

	Unit	Yr t N Cow 2 hd	Yr t NCow3 hd	… hd	Yr t NCow8 hd	… hd	Yr t N Hc hd	Yr t N Bc hd	Yr t N Hy hd	Yr t N Sty hd	Yr t+1 N Cow 2 hd	Yr t+1 N Cow 3 hd	… hd	Yr t+1 NCow 9 hd	… hd	Yr t+1 N Hc hd	Yr t+1 N Bc hd	Yr t+1 N Hy hd	Yr t+1 N Sty hd	sign	RHS
Yr t+1 trans N Cow 2 - 3	hd		-0.86									1								=	0
…	hd			…									…							=	0
Yr t+1 trans N Cow 8 – 9	hd				-0.86									1						=	0
Yr t+1 trans N Hc –N Hy	hd						-0.987											1		=	0
Yr t+1 trans N Bc – N Sty	hd							-0.95											1	=	0
Yr t+1 trans NHy – NCow 2	hd								-0.795		1									=	0

Abbreviations

N Cow 2	NFE 2 year old cows
N Cow (year)	NFE (year) old cows are 2 to 9 years old
N Hc	NFE heifer calves
N Bc	NFE bull calves
N Hy	NFE heifer yearlings
N Sty	NFE steer yearlings
Yr t	Year t
trans	Transfer to:
Yr t+1	Next year
N Ret Hc	Retain NFE heifer calves
N Sell Hc	Sell NFE heifer calves as weaners
Cull cows	Cull cows
Cull H	Cull heifers prior to entering breeding herd
H sales	Heifer weaner sales
St sales	Steer sales

For example: Yr t+1 trans N Bc – Nsty means: “current year’s NFE bull calves transfer to Next year’s steer yearlings”

Inter-year transfer ties for livestock enterprises sub-matrix

	Unit	Yr t SRM500 500hd	Yr t SRM hd	Yr t PL500 500hd	Yr t PL hd	Yr t MW500 500hd	Yr t MW hd	Yr t+1 SRM500 500hd	Yr t+1 SRM500 sell 500hd	Yr t+1 SRM hd	Yr t+1 SRM sell hd	Yr t+1 PL500 500hd	Yr t+1 PL500 sell 500hd	Yr t+1 PL hd	Yr t+1 PL sell hd	Yr t+1 MW500 500hd	Yr t+1 MW500 sell 500hd	Yr t+1 MW hd	Yr t+1 MW sell hd	sign	RHS
Tax I	$	11240	22.48	15390	30.78	9620	19.24	11240	-28225	22.48	-56.45	15390	-18200	30.78	-36.40	9620	-11040	19.24	-22.08	=	0
SRM500 T	hd	-1						1	1											=	0
SRM T	hd		-1							1	1									=	0
PL500 T	hd			-1								1	1							=	0
PL T	hd				-1									1	1					=	0
MW 500 T	hd					-1										1	1			=	0
MW T	hd						-1											1	1	=	0

Inter-year transfer ties for livestock enterprises sub-matrix (continued)

	Unit	Yr t VL100 100hd	Yr t VL hd	Yr t W100 100hd	Yr t W hd	Yr t YC100 100hd	Yr t YC hd	Yr t HFS30 30hd	Yr t HFS hd
Tax I	$	21658	216.58	6557	65.57	7503	75.03	2445	81.51
VL100 T	hd	-1							
VL T	hd		-1						
W100 T	hd			-1					
W T	hd				-1				
YC100 T	hd					-1			
YC T	hd						-1		
HFS30 T	hd							-1	
HFS T	hd								-1

Inter-year transfer ties for livestock enterprises sub-matrix (continued)

	Unit	Yr t+1 VL100 100hd	Yr t+1 VL100 sell 100hd	Yr t+1 VL hd	Yr t+1 VL sell hd	Yr t+1 W 100 100hd	Yr t+1 W 100 sell 100hd	Yr t+1 W hd	Yr t+1 W sell hd	Yr t+1 YC100 100hd	Yr t+1 YC100 sell 100hd	Yr t+1 YC hd	Yr t+1 YC sell hd	Yr t+1 HFS30 30hd	Yr t+1 HFS30 sell 30hd	Yr t+1 HFS hd	Yr t+1 HFS sell hd	sign	RHS
Tax I	$	21658	-74600	216.58	-746	6557	-75600	65.57	-756	7503	-106000	75.03	-1060	2445	-30690	81.51	-1023	=	0
VL100 T	hd	1	1															=	0
VL T	hd			1	1													=	0
W100 T	hd					1	1											=	0
W T	hd							1	1									=	0
YC100 T	hd									1	1							=	0
YC T	hd											1	1					=	0
HFS30 T	hd													1	1			=	0
HFS T	hd															1	1	=	0

Abbreviations

SRM500 T	Minimum Self-replacing Merino flock transfer
SRM T	Additional self-replacing Merino flock transfer
PL500 T	Minimum Prime lamb flock transfer
PL T	Additional Prime lamb flock transfer
MW 500T	Minimum Merino wether flock transfer
MWT	Additional Merino wether flock transfer
VL100 T	Minimum Cross-bred vealer herd transfer
VL T	Additional Cross-bred vealer herd transfer
W100 T	Minimum Store weaner herd transfer
W T	Additional Store weaner herd transfer
YC100 T	Minimum Young cattle herd transfer
YC T	Additional Young cattle herd transfer
HFS100 T	Minimum Heavy feeder steer herd transfer
HFS T	Additional Heavy feeder steer herd transfer
T	Transfer row

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