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A.R. Alford, G.R. Griffith and O.J. Cacho*

Abstract

Selection of beef cattle for increased net feed efficiency is a current major focus for research. At present the trait seems to be more apparent in Australia's southern beef production system which is dominated by mixed farming enterprises. Farm-level evaluation of net feed efficiency should take account of the farming system for which it is proposed along with the dynamic nature of genetic selection. Gross margin, linear programming and multi-period linear programming approaches to evaluation of the trait at the farm-level using a representative farm are compared. Implications of the trait for researchers and beef producers are identified.

Key words: farm-level evaluation, genetic traits, linear programming

Introduction

Declining terms of trade for Australian farmers necessitate the continual search for increased productivity through the application of "new" production technologies on the farm. Economic evaluation of these technologies is regularly used as a means of identifying the economic gains, both *ex ante* and *ex post*, from agricultural research. At one level, such assessments are becoming recognised as an essential component of research programs given the context of limited funding and the increasing pressure upon Cooperative Research Centres (CRCs), Research & Development (R&D) Corporations and the like to maximise the benefits to those funding investments in research. Producers still provide much of those funds. At the farm-level, evaluation of a new technology using linear programming has the ability to jointly evaluate concurrent farm activities, considering the costs and returns of all enterprises and the resource adjustment imposed by adoption of the technology (Griffith, Vere and Bootle, 1995).

The following analysis applies the Northern Tablelands Whole-Farm Linear Program (NTLP) and associated whole-farm budgets to estimate the likely economic benefits of one such technology; improved net feed efficiency in beef cattle. This technology has been a major research initiative of the Beef CRC, and the Northern Tablelands in New South Wales is one of the regions where the technology will be particularly applicable. The whole-farm focus incorporates various aspects of the pasture base, resource constraints and sheep and cattle interactions. It is intended that such a model can then be used along with other regional models in New South Wales for the economic evaluation of new technologies applicable to these grazing systems.

The paper proceeds by presenting background information on the evaluation of new technologies, beef farming in Australia and the region of interest. The NTLP is briefly described and extended into a multiperiod linear programming (MPLP) model. 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-

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optimality risk analysis with stochastic prices. The paper concludes by highlighting some key findings from the results of the study to date.

Evaluation of New Technologies 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 become more applicable to agricultural systems as meaning a "different way of doing things" (Anderson and Hardaker 1979, p.12), such as changing sowing and fertilizer rates or dates, or changing the timing of farm activities within the production year.

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 shift in the supply curve for the relevant commodity. The size of the shift in supply brought about by the adoption of the new technology is known as the K-factor. The shift in supply causes new equilibrium prices and quantities and consequently changes in the area of economic surplus. This 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).

Alston *et al*. (1995, p.328) suggest that K comprises two components: first, those changes in productivity that result when inputs are held constant at the level prior to the new technology; and second, the shift in supply that is a consequence of changes in the optimal input mix when the new technology is applied. They point out that the relevant K-factor measure at the farm-level is in fact that shift that results from the producer maximising their objective function, allowing the farm's input mix to be adjusted.

In practice the information required to undertake farm-level evaluation of a technology is not always immediately obvious. Pannell (1999) identifies categories of information that are applicable to the evaluation of technologies at the farm level. For evaluation of a technology at an individual farm level these relevant categories include:

- quantifying the biological, technical and/or management changes from the new technology;
- 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
- quantifying 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 (Pannell 1999).

Gross margin models can be used to effectively estimate within enterprise benefits while linear programming can accommodate whole farm benefits taking into account how a new technology is likely to fit into a whole-farm plan (Griffith *et al.* 1995). This is especially relevant given the diversification of enterprises amongst Australian broad-acre producers.

Beef Production in Australia

Beef cattle production occurs throughout all Australian states however it predominates in Queensland, with 40 per cent of the national herd, followed by New South Wales and Victoria with 24 per cent and 16 per cent of the national herd respectively. Of the 38,300 commercial farms in

Australia operating beef herds in excess of 50 head, 18,100 are specialist beef herds for which the average herd size is 832 head.

Two broadly defined beef production systems exist in Australia. These are based upon climatic conditions that along with proximity to markets dictate the management systems employed. The Northern system in the tropical regions and arid and semi-arid zones of northern Australia is typified by large herd sizes on native or semi-improved pastures. These farms generally only produce cattle, typically for manufacturing-grade beef, for finishing in southern regions or for live export. Approximately 64 per cent of the Northern herd are *Bos indicus* or *Bos indicus* cross cattle (ABARE 2001).

In contrast, the Southern production system has smaller herds, predominantly based upon British breeds, reared on semi-improved or improved pastures. More favourable climatic conditions and greater access to markets allow producers to target a wider range of beef markets. Frequently these farms also have opportunities to diversify into sheep and cropping activities. It is estimated that some 56 per cent of commercial beef cattle run in the Southern system are on mixed farms (ABARE 2001). This has implications for evaluating beef technologies in this zone.

Characteristics of the Northern Tablelands Farming System[1]

The Northern Tablelands region of New South Wales covers an area of approximately 3.12 million hectares including 2.11 million hectares occupied by agricultural establishments (ABS, 1998). This essentially equates to the northern portion of ABARE Region 131, the NSW Tablelands (S. Hooper, *pers com*). It is located between the latitudes of 28°15'S and 31°30'S and has an average elevation of 800 metres. Topography is undulating to hilly with rises to 1400 metres, and is a major limitation to the broad adoption of cropping enterprises in the region.

The climate of the region is characterised by high rainfall, with a summer-dominant pattern. However, high evaporation rates during summer limit the potential growth of pastures. Cold winter conditions, including a 200-day frost interval, limit growth from April through October (Hobbs and Jackson, 1977). Rainfall is variable with frequent seasonal droughts (ie, those extending for at least a six-month period). For example, such droughts occur 1 in every 3.5 years in the Glen Innes district (Clewett, Smith, Partridge, George and Peacock, 1999).

The major geological parent material from which soils in the Northern Tablelands are derived consist of granites, older Paleozoic rocks predominantly classified as greywackes, and tertiary basalts (Harrington, 1977). Apart from the basalt-derived soils, poor structure, drainage, and fertility of Northern Tablelands soils make them less suitable for cropping (McGarity, 1977). Further, the occurrence of high intensity rainfall from summer storm activity on the undulating to hilly topography increases the risk of erosion potential and thus the need for adequate ground cover.

The expansion of pasture improvement activities through the period 1950 to 1970 was important in improving the productivity of pastures in this region. Such activities included the application of superphosphate and the widespread introduction of new pasture species including legumes. An estimated 50 per cent of Northern Tablelands pastures are based upon natural pastures, a higher proportion than exists on tablelands regions further south (Duncan, 1995; Lodge and Whalley, 1989). It is estimated that introduced pasture species occupy only 23 per cent of the total farm area in the Northern Tablelands (Archer, 1995), a factor contributing to the well-known "winter feed gap" in this region.

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[1] See Alford, Griffith and Davies (2003) for more detail.

Given these natural resources the Northern Tablelands is dominated by sheep and cattle pastoral activities. In terms evaluating a new technology applicable to these pastoral activities, the impact of the technology on the pasture base and the effect on utilisation of that pasture is of importance.

The Technology - Net Feed Efficiency in Beef Cattle

Selection of beef cattle for increased feed efficiency is a relatively new research area that has been a major research focus for the Beef CRC. 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 successful within the monogastric poultry and pig industries.

Net feed efficiency (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).

Heritability of the NFE trait is moderate and of similar magnitude to the heritability of growth (Arthur *et al*. 2000). 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). The NFE trait has been extensively studied within British breeds of cattle and as such is directly applicable to the Southern beef production (Exton, Herd, Davies, Archer and Arthur, 2000).

Previous economic evaluations of NFE technology (Exton *et al*. 2000, Archer and Barwick 1999) have used gross margin (GM) and cashflow budgeting techniques to evaluate NFE, however these techniques do not account for the technology within a whole-farm context. This study undertakes evaluation of the NFE technology at the whole farm level using different versions of a whole-farm linear program specifically for the Northern Tablelands of New South Wales.

The Northern Tablelands Whole-Farm Linear Program

The Northern Tablelands linear programming model (NTLP) is derived from the Victorian Department of Natural Resources and Environment's whole-farm linear program for various pastoral regions of Victoria, as well as previous linear programming models, including Farquharson (1991). The NTLP model is constructed to represent a typical beef-sheep farm on the Northern Tablelands of New South Wales. The model is deterministic and based upon a single year in equilibrium for which 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.

The coefficients for animal feed requirements are based upon the metabolizable energy system, for various classes of livestock for each calendar month (MAFF 1975). The NTLP model incorporates more recent predictive equations from MAFF (1984) and refinements to this standard as described by McDonald *et al.* (2002) and SCA (1990). As well, enhancements as suggested by SCA (1990) that did not need more complex equations were also included, such as an increased maintenance allowance to account for the higher grazing effort under Australian conditions.

The pasture resources for the representative farm were determined from various pasture surveys undertaken in the Northern Tablelands (see Alford, Griffith and Davies, 2003), while pasture production and quality were derived from simulation modelling output from GrassGro™ (CSIRO,1999) and NSW Agriculture (1996).

The grazing enterprises included are those which are common amongst Northern Tablelands graziers, as identified by interviews with regional agricultural advisors and researchers. The management practices are based upon "best management practices" as described by NSW Agriculture officers and reported in NSW Agriculture Farm Budget Handbooks (Llewelyn and Davies, 2001; Webster, 1998). However, management targets may be altered in the model, such as herd or 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 some 129 activities and 70 constraints. Four sheep activities are available for selection including a self-replacing Merino ewe flock (19 micron), a Merino wether flock (19 micron), a second-cross prime lamb production activity and an activity that uses a Dorset terminal sire over a Merino ewe flock. The beef enterprise options include a "local trade" vealer enterprise; a store weaner production enterprise; a young cattle enterprise producing steers at 20 months (moderate growth) and a heavy feeder steer production enterprise.

A large number of the activities in the matrix are related to feed transfers between months and fodder conservation actions. The supplementary feeding of livestock also necessitates significant detailing. Following the method used to outline the MIDAS model (Kingwell, 1987), Table 1 provides an overview of the general structure of the NTLP matrix and the proportion of activities and constraints allotted to various components of the linear program. The NTLP is developed in an Excel™ spreadsheet (Microsoft Corporation, 2002) and solved using the optimizing add-on software What's Best™ (Lindo Systems, 1996). Further details are available from the author.

Implementing the NFE Technology

NFE improvement assumptions within a commercial beef herd were derived from Exton *et al.* (2000). The herd's increased NFE after year 25 is 6.9 per cent. This is based upon the assumption that 4 per cent genetically superior NFE bulls over an unimproved beef cow herd results in an annual improvement of 0.3 per cent in the cow herd's NFE and that the benefits in NFE are divided between maintenance and growth 70:30 (Exton *et al.* 2000). This increase in efficiency in the cow herd and growing stock was implemented in the NTLP by altering the efficiency of utilisation parameters of metabolizable energy for animal maintenance and growth known as k_m and k_g respectively (SCA 1990), for each year over 25 years.

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

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).

Table 1. Outline of the structure of the Northern Tablelands Whole-farm Linear Program matrix

ACTIVITIES

CONSTRAINTS		Choose Sheep enterprises (4)	Choose Cattle enterprises (4)	Casual Labour Requirement (1)	Pasture types (3)	Pasture feed consumed or transferred (72)	Hay/Silage activities - make/ buy/sell (6)	Feed out fodder (4)	Buy/feed grain (12)	Sell animal products (23)	Sign	RHS term
Land area (1)	Ha				1						=	Area
Pasture type areas (3)	Ha				1						<=	Area
Fodder ties (2)							1				<=	Area
Fodder pools (2)	MJ						-a, +a	+a			<=	0
Pasture production (3)	MJ				-a	+a, -a					<=	0
Feed Pool (12)	MJ	+a	+a			-a		-a	-a		<=	0
Max. Dry Matter Intake (12)	T DM	+a	+a			-1		-1	-1		>=	0
Labour constraints (12)	Hrs	+a	+a	-1							<=	Max permanent labour
Animal Outputs (23)	Kg or Head	-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.
Outline follows Kingwell (1987).

Alternate Versions of the NTLP

The optimal farm plans, which included a commercial beef producing herd, for the without-NFE case (Base) and with-NFE case were generated by conducting several modelling experiments varying in complexity. These included a single-year equilibrium whole-farm model and a multi-period whole-farm LP to examine further the investment in the genetic technology which is obviously time-dependent.

The whole-farm single-year equilibrium model 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) assesses the use of a hormone vaccination to induce twinning in cattle using this approach. 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 a technology. 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 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 within the multi-period model. Some initial results of the multi-period model follow.[2]

Maximising Discounted Total Gross Margins

In the first experiment the multi-period model based upon a 25-year time frame was optimized for the discounted sum of annual total gross margin (TGM) for the representative farm. The optimal farm plan for the base case (without the NFE technology) was 1115 Prime Lamb producing ewes, 2476 19-micron Merino wethers and a cow herd of 110 unimproved cows producing young cattle to turn off at 20 months of age (Table 2).

Next the NFE cow enterprise was included in the model and the initial (year 1) enterprise mix was set the same as the base case (1115 Prime Lamb producing ewes, 2476 19-micron Merino wethers and 110 unimproved cows) however in Year 1 NFE bulls were selected by the MPLP to put over the cow herd. Over the 25-year planning horizon the various livestock enterprises adjusted so that by year 25 the optimal farm plan was 1115 Prime Lamb producing ewes, 2277 19-micron Merino wethers and a herd of 123 NFE cows, an increase in cattle of 12 per cent by year 25 (Table 2). This equated to an improvement in the NPV per breeding cow per year over the base herd of $9.59, using a 5% discount rate. This compares with the calculated NPV per breeding cow per year estimated by Exton *et al.* (2000) of $6.95. In contrast to the 12 per cent increase in cow numbers found here, the previous study using gross margin and cashflow budgets allowed for an increase of 10 per cent. The LP approach allowed for input substitution, where resources are diverted away from the Merino wether enterprise towards the new NFE cattle enterprise. 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. A number of factors are evident from the LP results that suggest that the NFE technology may be of greater benefit to the Northern Tablelands representative farm than indicated by a general budgeting approach.

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[2] See Alford, Griffith and Cacho (2003) for the results from the LP and a comparison with the gross margin and discounted cash flow analyses.

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.

From an examination of the LP results it is observed that the LP seeks to maximise TGM over the 25-year period by initially investing in NFE-superior bulls over the cow herd, resulting in increased efficiency of the herd and their growing offspring. Table 3 shows a selection of model constraints and shadow prices of bound constraints. Supplementary grain feeding is binding in year one, however, the shadow price associated with this constraint in the case of the farm plan with the NFE technology is higher ($83.79/t) than in the base case ($64.09/t). This reflects the greater potential 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 Table 3 energy from the perennial pasture is a binding constraint in both models, with the shadow prices for perennial pastures in July, for example, with the NFE technology being higher ($0.012/MJ) than for the base case ($0.008/MJ) when the technology is unavailable. This phenomenon of higher shadow prices for feeds as a result of seasonal fluctuations in pasture growth is described by Pannell (1999).

Table 2. Optimal farm plan for a without (Base) and with-technology (NFE) farm in year 25

Enterprise	*Unit*	*Base*	*NFE*
Prime Lamb	Ewes	1 115	1 115
Merino Wethers	Wethers	2 476	2 277
Unimproved Cow Herd	Breeding cows	110	-
NFE Cow Herd	Breeding cows	-	123
Objective Function[1]	$	1 432 737	1 452 547
PV (including livestock capital[2])	$	1 493 898	1 520 267
Difference in NPV	$	-	26 369
Difference in NPV / breeding cow/year (NPV/110cows/25 years)			$9.59

[1] Present value of accumulated Total Gross Margins discounted at 5%.

[2]Salvage value assumptions regarding livestock assets of the farm plan include nominal values for the different classes of livestock including Prime Lamb producing ewes, $55/hd; Merino wethers, $40/hd and unimproved cows, $425/hd and NFE cows at year 25 valued at $475/hd. Capital values used for the cow herd follow those assumed by Exton *et al*. (2000).

Table 3. Comparison of some binding and slack constraints in the linear program solutions for the with NFE and without farms

Constraint		Unit	Binding (B) or Slack (S)		Amount of Slack		Shadow Price[1]	
			NFE	Base	NFE	Base	NFE	Base
Yr 1	Supplementary grain	tonnes	B	B	-	-	83.79	64.09
Yr 25	Supplementary grain	tonnes	S	B	4.17	-	-	19.87
Yr 1	Perennial pasture June	MJ[2]	B	B	-	-	0.008	0.005
Yr 1	Perennial pasture July	MJ[2]	B	B	-	-	0.012	0.008
Yr 1	Perennial pasture August	MJ[2]	B	B	-	-	0.012	0.006

[1] Shadow prices reflect the 5% discount rate used.

[2] Model assumes 50% pasture utilisation, therefore shadow prices can be divided by 50% to obtain indicative price per ME to the animal.

The optimal farm plan invests 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. The farm plan reaches a steady state by year 16 (Figure 1). At this point the marginal costs of other farm activities become greater and the model achieves additional savings through reduced supplementary feed and casual labour costs beyond this point (Figure 2).

Figure 1. Changes in herd and flock sizes on the representative farm over 25 years

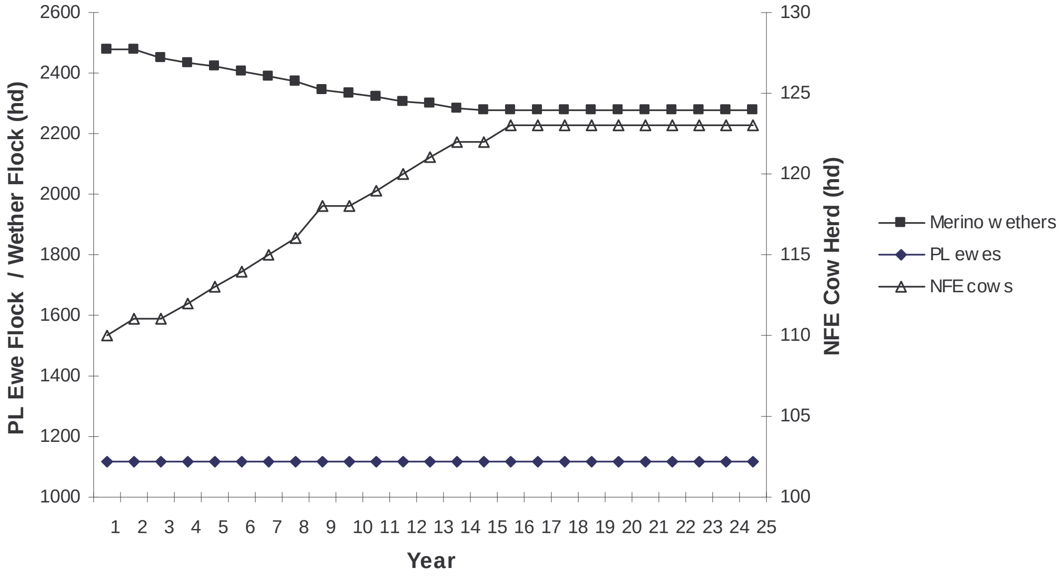
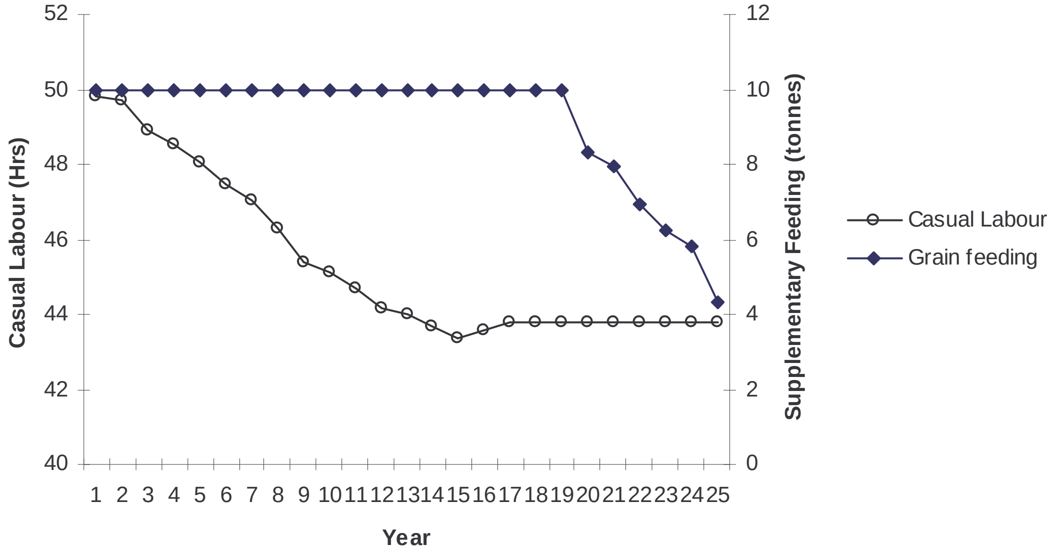


Figure 2. Representation of the use of casual labour and supplementary grain inputs over the 25-year period under the optimal plan with the NFE trait available to the farm



Maximising Farm Net Worth

In the second series of experiments the whole-farm model was expanded to include fixed costs and family drawings for the representative farm (Table 4). These values were determined from ABARE survey data for the region and from several cooperating district farmers. Assumptions regarding the level of debt and a simple taxation component were included in the model. The objective function for the whole-farm LP was then set at maximising net worth of the farm household. Therefore a discount rate did not have to be assumed.

Table 4. Assumed whole-farm budget components

Overheads + Depreciation ($)	39 000
Family drawings ($)	35 000
Credit interest rate	0.05
Overdraft interest rate	0.09
Overdraft Account ($)	30 000
Value of Plant and Land ($)	1 254 000

The broad result from this modelling exercise, given the overhead, capital and family drawing constraints, was that the NFE technology was initially selected only over a portion of the herd. Some key output for the representative farm is provided as an example (Figure 3 and Table 5). The farm plan initially included the NFE technology being invested only over 30 breeding cows, however this progressively increased over the entire herd to reach a herd size of 147 cows by the final year. The Prime Lamb enterprise remained unchanged while the wether enterprise decreased from the initial 2476 to 2026 wethers by the final year. The final difference in net worth of the farm business with the NFE technology compared to the without-NFE technology case, is $32 957 for the representative farm or $299.61 per breeding cow (based upon the original 110 cow herd).

Figure 3. The optimal farm plans over time with the NFE technology and with overhead, capital and family drawing constraints

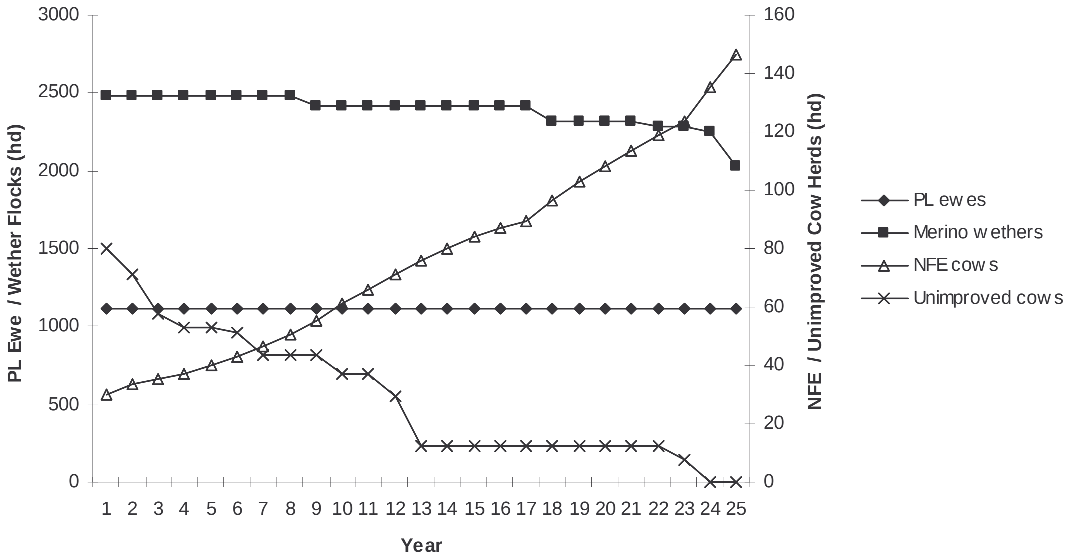


Table 5. Results when optimising net worth

	$
Net Worth, with NFE available	1 556 490
Net Worth, without NFE	1 523 533
Change in Net Worth	32 957
Net worth improvement per cow (original herd size)	299.61
Terminal value assumptions:	
Land, plant and machinery	1 254 000
NFE Cows	801
Unimproved cows	738
Prime Lamb ewes	57.91
Merino wethers	25.30

Livestock values are x 1.25 cull sale price (including followers) and $50 premium attached to NFE cows

Terminal valuations of the livestock assets were initially set at their equivalent cull prices with a $50 premium attached to the NFE cows following Exton *et al.* (2000). However a range of terminal asset prices for the livestock were tested given the apparent sensitivity of the technology evaluation results to these assumptions. Terminal values were chosen based on multiplying (×1.0, ×1.25, ×1.5, ×1.75, ×2.0) the cull value of the animals, including followers, and setting a nominal value for the NFE cows above the unimproved cows. The results of the analysis in Table 5 and Figure 3 use terminal values based on a multiple of 1.25.

Results (Table 6) 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. This divergence in the optimal herd size as the model approaches year 25 depending upon the terminal values used (SV) is

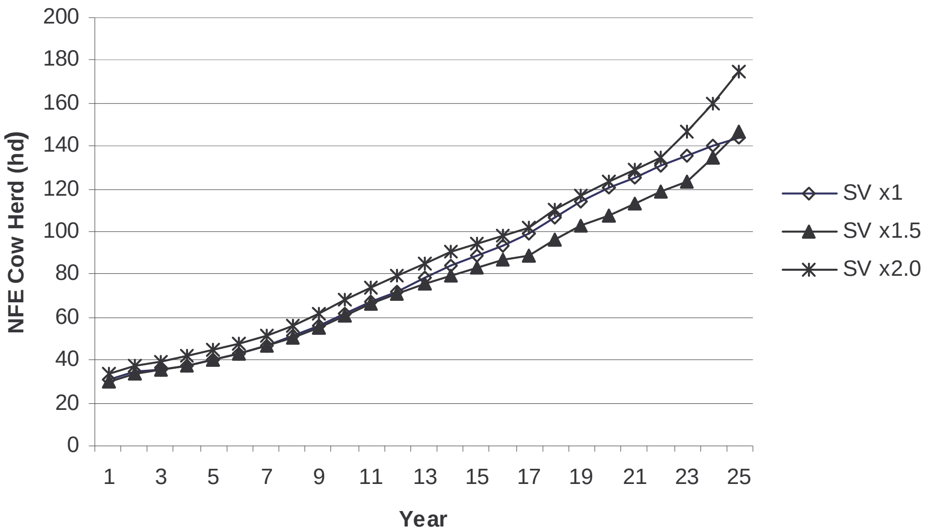
Table 6. **The change in farm net worth and optimal plan for different terminal asset prices**

	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 ($m)	1.480	1.510	1.523	1.556	1.566	1.603	1.609	1.649	1.652	1.697
Change in Net Worth ($)		29 504		32 956		36 613		40 241		45 170
Change in Net Worth per cow ($)		268		300		333		366		411
Optimal Enterprise Mix in Year 25										
NFE Cows (breeding cows)		144		147		147		175		175
Prime Lambs (ewes)		1 115		1 115		1 000		1 000		1 000
Merino wethers (head)		2 049		2 026		2 025		1 616		1 616

illustrated in Figure 4. At the highest terminal values tested (×2.0) the optimal herd size is 175 cows, an increase of 59 per cent over the base herd size. This compares with a 31 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 long-term environmental issue assessment models, the optimal results can be artificially affected by the valuation of assets in the distant future, known as the "age effect". This problem was described by Boussard (1971) in using linear programming models for long-term farm planning 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.

Figure 4. The optimal growth in the NFE cow herd for different terminal asset prices



Post-Optimality Risk Analysis

The degree of risk and farmer's risk aversion 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 addressed by Pannell, Malcolm and Kingwell (2000, p.75) who 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".

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 we present a preliminary post-optimality risk analysis based on price probability distributions. This analysis is based on the first MPLP, where NPV of TGM is maximised.

Monthly price data over the period 1980 to 2000 for New South Wales, for the livestock classes selected in the optimal farm plan, were examined (AMLC, 1997; MLA, 2001). All prices were adjusted to 2001 dollars. A long price series was used given the 25-year planning horizon used in the LP model. However, a shorter 10-year time frame post the abandonment of the Wool Reserve Price Scheme from 1991 to 2001 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. These were applied (Table 7) and simulations 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 the equivalent to correlation coefficients, correlation coefficients were determined from the price series data for the various outputs (Table 8) to assist in attributing rank order correlations. The rank order correlations used in @ Risk were 0.9 between beef cattle prices, 0.75 between the various sheep prices and 0.5 between the sheep and cattle prices. A correlation of 0.4 was applied between the 19-micron and 27-micron wool prices.

An examination of the simulation results summary (Table 9) and the resulting cumulative distribution functions (Figure 5) suggests that the without-technology plan has a lower average total gross margin, a lower minimum total gross margin and a more variable total gross margin. The cumulative distribution function diagram indicates that the without-technology plan is dominated by the with-NFE farm plan using the second degree stochastic dominance criterion. Therefore, the optimal farm plan incorporating the NFE does not increase income risk from output price variability. 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 7. Examples of price distributions used in the risk model

Price variable	Distribution	Price variables (minimum, most likely, maximum)	
20 m.o steer	Triangular	68, 165, 310	c/kg liveweight
18 m.o heifer	Triangular	55, 142, 285	c/kg liveweight
Cull cows	Triangular	42, 95, 224	c/kg liveweight
Prime lambs	Triangular	53, 98, 1.52	c/kg liveweight
Wethers	Triangular	5, 45, 1.32	c/kg liveweight

Table 8. Correlation coefficients* between various output prices from the representative farm

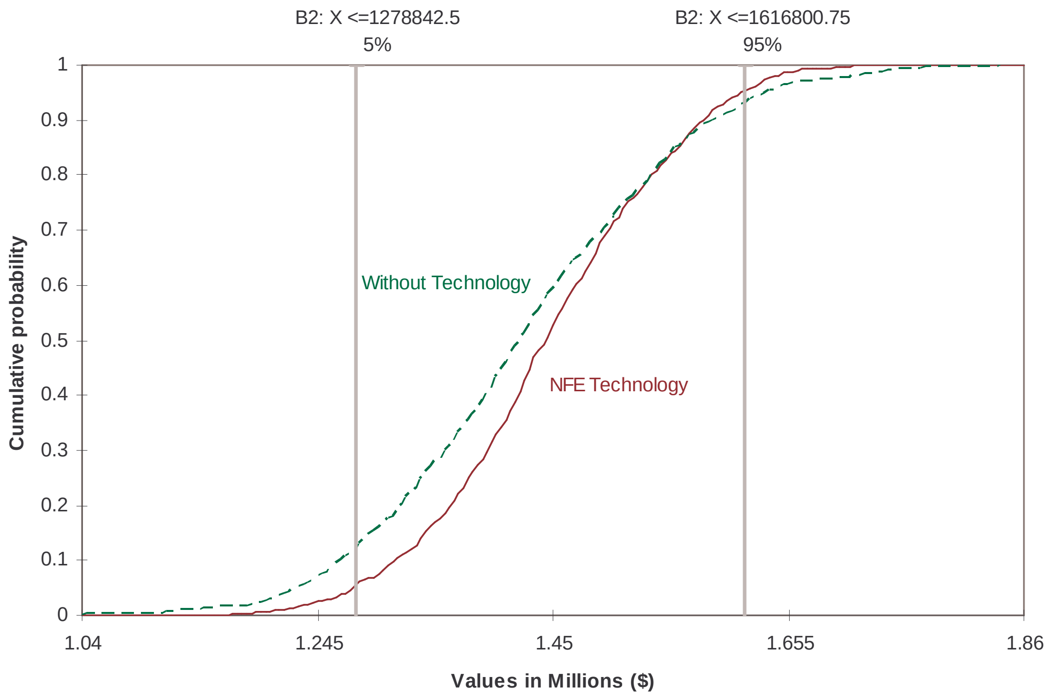
	Steers 28 - 30	Steers 32-40	Cows 22 - 26	Young cattle to 20	Lambs 8-16	Wethers 8-22
Steers 28 - 30	1	98.3	95.2	95.4	46.7	44.0
Steers 32-40		1	95.4	94.9	39.4	35.8
Cows 22 - 26			1	94.8	52.5	55.9
Young cattle to 20				1	52.9	51.9
Lambs 8-16					1	83.8
Wethers 8-22						1

*Correlations based on NSW monthly price data, 1979 to 2000 (MLA 2000)

Table 9. Summary results of @Risk simulation

	Without- technology Plan	With NFE technology
Distribution measure	$	$
Mean	1 430 272	1 449 602
Minimum	1 043 180	1 121 072
Maximum	1 855 351	1 735 203
Standard Deviation	127 026	101 556

Figure 5. Comparison of the cumulative distribution functions for without- and with-NFE Technology optimal farm plans based upon the sum of total gross margins over the planning period



Conclusion

The benefits of evaluating a new technology in a whole farm context using a linear programming framework are well known. Compared to using a standard enterprise gross margin approach, evaluation of a new technology using linear programming has the ability to jointly evaluate concurrent farm activities, considering the costs and returns of all enterprises and the resource adjustment 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.

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. 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.

Second, in terms of the NFE technology, 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 overhead and capital constraints of an individual farmer in adopting a technology.

Fourthly, 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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