An Assessment of the Economic, Environmental and Social Impacts of NSW Agriculture's Investment in the Net Feed Efficiency R,D&E Cluster

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Abstract: In 2003 the economic, social and environmental impacts of five areas of research and extension, where NSW Agriculture has made significant investments, were evaluated. These investment areas included net feed efficiency in beef cattle; the management of weeds in temperate pastures; conservation farming in the northern NSW cropping zone; wheat breeding in NSW; and extension in water use efficient technologies. The benefit cost analyses were conducted over the period from 1980 to 2020. For the net feed efficiency cluster of projects, the benefits to all recipients in southern Australia were $158.0 million and the costs incurred by all R,D&E suppliers were $20.6 million, resulting in a Net Present Value of $137.4 million, an Internal Rate of Return (IRR) of 13 per cent and a Benefit Cost Ratio (BCR) of 7.7. Comparing the benefits to NSW producers relative to the costs incurred by NSW Agriculture resulted in an NPV of $65.1 million, an IRR of 9 per cent and a BCR of 5.6.

Keywords: benefit cost analysis; research evaluation; extension evaluation; net feed efficiency

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Acronyms and Abbreviations Used in the Report

ABARE	Australian Bureau of Agricultural and Resource Economics
ALFA	Australian Lot Feeders Association
AMLC	Australian Meat and Livestock Corporation (now part of MLA)
BCR	Benefit Cost Ratio
CRC I	Cooperative Research Centre for the Cattle and Beef Industry
CRC II	Cooperative Research Centre for Cattle and Beef Quality
DSE	Dry Sheep Equivalent
EBV	Estimated Breeding Value
FTE	Full Time Equivalents
GGAP	Greenhouse Gas Abatement Program
GHG	Greenhouse Gases
GM	Gross Margin
HFS	Heavy Feeder Steers
IRR	Internal Rate of Return
LP	Linear Programming
ME	Metabolisable Energy
MIDAS	Model of an Integrated Dryland Agricultural System
MJ	Megajoules (of energy)
MLA	Meat and Livestock Australia
MRC	Meat Research Corporation (now part of MLA)
NFE	Net Feed Efficiency
NPV	Net Present Value
NTLP	Northern Tablelands Linear Program
NTMP	Northern Tablelands Multi-Period Linear Program
R,D&E	Research, Development and Extension
SV	Salvage Value
TGM	Total Gross Margin

Executive Summary

This report presents the results of one of a suite of five evaluations conducted in 2003 in the former NSW Agriculture[1] into significant areas of research and extension investment. The particular area of investment examined here is net feed efficiency in beef cattle.

Description of Net Feed Efficiency

Feeding cattle is a major cost of beef production. In southern Australia, beef cows and their progeny are generally run on improved pastures until they are either sold direct for slaughter or as store cattle for subsequent finishing on pasture, or in feedlots. The cost of developing and maintaining improved pasture ranges between $7.50 and $12.86 /DSE/year depending on area sown and stocking rate. In a typical enterprise targetting the domestic supermarket trade, the lower estimate means that 60 per cent of the variable costs of production are related to feed cost. Supplementary feeding with hay, grain and silage is often necessary to fill feed gaps for cows on pasture and to ensure young cattle grow to specification. Such supplementation adds further to the cost of feeding cattle. Further, the cost of feed accounts for 70 per cent of the variable cost of operating a feedlot.

Net feed efficiency (NFE) refers to the efficiency of feed utilisation assessed after accounting for the requirements for growth and maintenance of body tissue, and is calculated as residual feed intake. This is simply the difference between an animal's actual feed intake and its expected feed requirements for maintenance and a particular growth rate. Genetic selection for improved feed efficiency aims to reduce feed-related costs and thereby improve profitability.

The former NSW Agriculture commenced R,D&E in this area in the early 1990s, with a major project funded by the Meat Research Corporation (MRC). Since then, NFE has been part of the research program of the Cooperative Research Centre for the Cattle and Beef Industry (CRC I) and the Cooperative Research Centre for Cattle and Meat Quality (CRC II). Recently, research has commenced on the relationship between NFE of cattle and output of greenhouse gas (GHG), where the experimental work has focussed on evaluating breeding for improved NFE as a GHG abatement strategy.

This area of research began in NSW Agriculture and the Department remains a key player, recognised worldwide as a leader in the science of NFE.

Approach to evaluation

The evaluation was approached in two parts. First, an attempt was made to properly account for all of the resources employed in this R,D&E cluster.

The total value of inputs to this NFE R,D&E cluster of projects were estimated to be $20.6 million between 1991/92 and 2019/20. For NSW Agriculture expenditures, actual project payments were taken from MRC and CRC documentation. Estimates were made of the full-time equivalent (FTE) staff of different categories involved in the NFE cluster of projects over the various periods of time they were in operation, and in some, expected maintenance

[1] This work was done prior to the formation of the NSW Department of Primary Industries (on July 1, 2004) through an amalgamation of NSW Agriculture, NSW Fisheries, State Forests of NSW and the NSW Department of Mineral Resources.

R,D&E out to 2020. The 2002 costs for representative FTEs were calculated as salary plus on-costs of 23 per cent. The total cost of these NSW Agriculture inputs was estimated as $13.9 million on a present value basis using a 4 per cent real discount rate.

For external funding, actual project payments were taken from MRC/MLA and CRC documentation where appropriate. An estimate was also made of the contributions of Breed Society extension officers to this cluster. The total cost of these inputs from external sources was estimated as $6.7 million on a present value basis. Thus of the total value of inputs into this R,D&E area, NSW Agriculture contributed over two-thirds.

Second, an attempt was made to estimate the economic, environmental and social benefits of the potential adoption of the NFE technology in the Southern Australian beef industry. The economic benefits at the farm level were assessed by the use of a whole-farm linear program representing a typical mixed beef-sheep farm on the Northern Tablelands of New South Wales. Gross margin budgets were developed for the NFE cow enterprise and the cow enterprise it would be expected to replace and account was taken of the dynamics of the herds over time. The farming system was simulated under both possible enterprise combinations and the financial outcomes of the farming system were compared. In making these comparisons, a very conservative approach to modelling the uptake of the NFE genetics was followed to allow for any potential unfavourable but as yet unknown relationships between NFE and other traits. Models were also calculated to assess the impact of NFE cattle in a feedlot situation.

Economic, environmental and social effects

The outcomes of this R,D&E cluster can be grouped as economic, environmental and social. The main outcomes of this R,D&E cluster to date have been economic. Genetic variation in residual feed intake exists, the trait is moderately heritable (around 0.4), and selecting high efficiency bulls will produce calves, steers and cows that are more feed efficient on pasture and in the feedlot. Further, where it has been formally measured, there does not seem to be any significant adverse implications for other traits of commercial importance. Thus breeders can select for NFE and growth and meat quality and not have to make any significant trade-offs. The scenario for the cattle industry without access to the NFE technology would be that productivity would improve based on past and easily forecast rates of genetic gain. The NFE technology is taken to provide an additional improvement above that already filtering through from past R,D&E.

This information has been taken up by the Australian stud cattle industry, and estimated breeding values (EBVs) have been made available in some breed societies to assist commercial producers introduce NFE-superior genetics into their herds. The adoption process has commenced, although only at very modest levels to date.

An on-farm testing facility has been devised so that cattle breeders can measure and monitor their herd with respect to NFE. Unfortunately, such a facility is costly to purchase and there is a high opportunity cost in allocating breeding stock to intensive feeding trials. However, new research is examining a simple blood marker test as a way of differentiating between NFE efficient and inefficient breeding stock.

The economic benefits of the widespread adoption of this technology throughout the southern Australian cattle herd was estimated to be an improvement in the net present values (NPVs) per breeding cow per year over the base herd of $6.55, evaluated at a discount rate of 4 per cent. This per cow benefit was multiplied by the number of breeding cows in the southern Australian beef herd, and then by the assumed adoption rate of the technology to generate an aggregate value of $128.6 million for the cow-calf component of the southern herd. The increase in the asset value of the southern herd over time as the NFE trait diffuses through the breeding herd has been included in these calculations. For the feedlot sector, it was estimated that the savings in feed costs in a feedlot in southern Australia due to the introduction of NFE cattle would be $4.34 per breeding cow per year, or an aggregate value of $29.4 million. Adding these components together, the total estimated benefits from the adoption of the NFE technology were calculated to be $158.0 million over the period 2003-2020.

In addition, the NFE technology has some quite positive but potential environmental outcomes. If a cattle producer introduces genetics with superior NFE, then over time the herd will require less feed to maintain the same herd size and farm income. This may result in a lower stocking rate and may provide some environmental benefits to the farm in terms of better ground cover, greater water holding capability and less grazing pressure on preferred pasture species. Superior NFE cattle will also produce less manure and urea and more easily cope with drought conditions. More promising though is the potential reduction in GHG emissions from more feed efficient cattle. Selecting for improved NFE will reduce GHG.

Social outcomes from the R,D&E in this area of work are more difficult to identify and to quantify. Because the technology has been developed in Australia, the beef industry will be less dependent on imported genetics. This may result in more vibrant breed societies and industry organizations, and perhaps greater export opportunities. Since cattle selected for NFE can cope more readily with dry conditions, the beef industry would not be as adversely effected by droughts and this may provide some social benefits during such times.

Comparing the benefits to all recipients in southern Australia relative to the costs incurred by all R,D&E suppliers resulted in a NPV of $137.4 million, an internal rate of return (IRR) of 13 per cent and a benefit cost ratio (BCR) of 7.7. Comparing the benefits to NSW producers relative to the costs incurred by NSW Agriculture resulted in an NPV of $65.1 million, an IRR of 9 per cent and a BCR of 5.6.

Funders and beneficiaries

It was noted above that of the total value of inputs into this R,D&E area, NSW Agriculture has contributed over two-thirds. Although there may have been good reasons for the mostly public funding in the early years of the research, the current mix of funding may now be too heavily weighted towards public funds. Those components of the NFE R,D&E cluster that generate essentially private benefits to the cattle industry and cattle producers should be increasingly funded by those groups. The environmental components of the work should however be mainly funded by the public sector as the majority of benefits will accrue to society at large.

1. Introduction

This report presents the results of one of a suite of five evaluations conducted in 2003 in the former NSW Agriculture[2] into significant areas of research and extension investment (Mullen, 2004). The five areas of investment evaluated are:

- Wheat breeding;
- Extension in water use efficiency;
- Net feed efficiency in beef cattle;
- Conservation farming and reduced tillage; and
- Management of the annual grass weed *vulpia.*

This suite of evaluations is designed to assess the economic, social and environmental impacts of these key areas of investment. It is anticipated that each year another set of investment areas will be evaluated. This evaluation process serves a number of purposes.

One is an external requirement for accountability in the way that the NSW Department of Primary Industries uses the scientific resources in its care. The NSW Department of Primary Industries currently invests about $100 million per year in research, extension and education activities making it the largest provider of research and development services within the NSW government sector. The opportunity cost of these investments is the benefits to the people of NSW if the funds were used in other areas such as health and education. Hence it is important that the NSW Department of Primary Industries can demonstrate that it uses these resources in ways that enhance the welfare of the people of NSW.

This evaluation process can also be used within the NSW Department of Primary Industries to assist in allocating resources to areas likely to have high pay-offs and to assist in designing research and extension projects that have clearly defined objectives consistent with the role of a public institution like the NSW Department of Primary Industries. In our view it is these internal applications that justify diverting resources to this type of evaluation process.

We would like to be able to value all economic, environmental and social impacts and relate these to the investments made. However in general we are only successful in valuing some of these impacts because of:

- uncertainty about the impact of the technology on farm production, both now and in the future;
- uncertainty about environmental and social impacts, both now and in the future;
- uncertainty about the value of environmental and social resources, both now and in the future; and
- limited resources to undertake these evaluations.

Our approach has been to first describe qualitatively the economic, social and environmental impacts of the actual or proposed investment. We also describe the rationale for government investment from a market failure point of view that seeks to identify the characteristics of the investment resulting in farmers individually or collectively under-investing in the areas under

[2] This work was done prior to the formation of the NSW Department of Primary Industries (on July 1, 2004) through an amalgamation of NSW Agriculture, NSW Fisheries, State Forests of NSW and the NSW Department of Mineral Resources.

consideration. We examine the share of public and private funding in the investment and compare this to a qualitative assessment of whether the benefits from the investment flow largely to farmers or largely to the community.

We then attempt to quantify as many impacts as practicable to arrive at one of the common measures of economic performance such as a benefit cost ratio. There are insights to be gained from persevering with an empirical benefit cost analysis even under hypothetical scenarios. A key step is to identify not only the expected impact on an industry of the investment (the ‘with technology’ scenario), but just as importantly, how the industry would continue to develop without the investment by the NSW Department of Primary Industries (the ‘without technology’ scenario). Rarely is the ‘without technology’ scenario a no-change scenario. This quantitative approach also gives an indication of the relative importance of key parameters such as the rate and extent of adoption of technology, the on-farm impacts, and the size of the investment and its time path.

In assessing the ‘with’ and ‘without’ technology scenarios, key outputs from research and extension activities and communication strategies used are described to give credence to claims about the contribution of NSW Agriculture and to assumptions about the rate and extent of adoption of the technology.

Research and extension investments are made at a project level but many small projects have similar objectives and hence our aim is to evaluate clusters of these projects. In this report the term project most often refers to a cluster of similar projects.

2. The Net Feed Efficiency Cluster

In this section we provide a broad description of the problem, inputs, outputs and outcomes associated with the net feed efficiency research and extension cluster of projects.

Net feed efficiency (NFE) refers to the efficiency of feed utilisation assessed after accounting for the requirements for growth and maintenance of body tissue, and is calculated as residual feed intake. It is a useful way of assessing variation in feed efficiency that is independent of (ie. net of) size and growth rate.

Feed costs are the major cost of beef production. Genetic improvement in feed efficiency can reduce feed required per unit of beef produced and thereby improve profitability, can increase the flexibility in the management of cattle, and can reduce environmental impacts. Outcomes from the R,D&E cluster should be improved cost competitiveness in export markets and improved farm business profitability and sustainability for southern Australian beef producers.

In the estimation of the costs and benefits associated with this R,D&E cluster, we take 2002 to be the "base" year. This means that information available as at the end of 2002 is used to specify the inputs, outputs and outcomes relating to this area of R,D&E. Some proposed investments such as the renewal of the Beef CRC and some new outcomes such as the release of the IGF-I blood test for NFE have been deliberately excluded.

2.1 The Research Problem

Feeding cattle is a major cost of beef production. In southern Australia, beef cows are predominantly run on pasture. Their progeny are generally run on improved pastures until they reach a specified live weight after which they are either sold direct for slaughter, or as store cattle for subsequent feeding on pasture, or in feedlots, to a specified market live weight and fatness. Farquharson *et al.* (2003, Appendix 4) have estimated that the cost of developing and maintaining an improved pasture ranges between $7.50 and $12.86/DSE depending on area sown and stocking rate. In an Angus supermarket enterprise, even using the lower estimate of $7.50/DSE means that 60 per cent of the variable costs of production are related to feed cost (Farquharson *et al*., 2003, Appendix 6).

Supplementary feeding with hay, grain and silage is often necessary to fill feed gaps for cows on pasture and to ensure young cattle grow to specification. This may be especially relevant in particular regions or at particular times of the year. An example is the well-known "winter feed gap" on the Northern Tablelands (Alford, Griffith and Davies, 2003). This supplementation adds further to the cost of feeding cattle.

Finally, the cost of feed is around 70 per cent of the variable cost of operating a feedlot.

Genetic selection for improved feed efficiency aims to reduce this cost of production and thereby improve profitability.

2.2 History and Objectives of the Net Feed Efficiency R,D&E Cluster

A comprehensive investigation of the consequences of selection for growth rate in beef cattle (the DAN 8 project) had been conducted at Trangie Agricultural Research Centre during the

1980s. An observation made during the latter stages of this study was that there were large differences between individual animals in their efficiency of feed use, independent of differences in body weight and growth rate. For example, some cows required up to 50 per cent less feed per kg of calf weaned than other cows of similar size from the same selection line. These findings were consistent with several overseas studies conducted at about the same time (NSW Agriculture, 1992, Appendix 1).

A major research project was proposed (NSW Agriculture, 1992) that had the following specific objectives:

- To demonstrate realised genetic responses and determine genetic and phenotypic parameters for post-weaning NFE;
- To provide the first progeny test evaluations for NFE among contemporary Angus and Hereford sires;
- To demonstrate correlated responses and determine genetic and phenotypic relationships between post-weaning NFE and calf growth performance, body composition, cow reproductive and maternal performance, mature cow feed costs, and steer feedlot performance, carcase yield and meat quality;
- To provide recommendations on the benefits of central progeny testing for NFE; and
- To provide a pilot facility for commercialised central NFE testing.

That is, to find out whether NFE is heritable, whether there are correlations with other traits (favourable or unfavourable), and what it would cost to identify this trait.

Given acceptable answers, the expected benefits from buying bulls that are genetically-superior for NFE are that their progeny will require less feed without compromise in growth performance and with no adverse effect on other traits such as carcase value and reproductive performance. As genes for superior feed efficiency spread through the herd, a profit-maximising commercial cattle producer should be able to run more cows and calves on the same area of pasture and with the same inputs of supplementary feed as previously required for the unimproved herd. Or, a producer with a different objective function could run the same number of cows and calves on a smaller area with lower inputs of supplementary feed to generate the same farm income. The surplus area could be allocated to other enterprises or to natural resource management activities such as windbreaks, wildlife corridors or water management systems.

The rate of improvement in efficiency within a herd depends upon the flow of superior genes for efficiency from the sire to his progeny, the rate of replacement of old cows by heifer progeny, and the rate of genetic improvement in the seedstock (or stud) herds from which the sire is purchased. This leads to faster rates of improvement in efficiency in young cattle for slaughter compared with that in the cow herd. Further, the economic benefit following the purchase of bulls that are genetically superior for efficiency will be cumulative over time.Its evaluation must include realistic estimates for the different rates of genetic improvement within the seedstock industry and within the commercial herd over time.

It was considered at the time that this NFE research project was developed that it should be jointly funded by the former NSW Agriculture and the cattle industry (NSW Agriculture, 1992). NSW Agriculture was the only research organisation in Australia doing any work on NFE at the time, and had a set of unique resources and skilled staff at Trangie Agricultural Research Centre suitable for the conduct of the project. The Meat Research Corporation (MRC) was an appropriate co-investor since the adoption of the research results would be likely to provide significant economic benefits to a wide range of cattle producers. It was considered unlikely that any private firms would invest to generate information for incorporation into industry breeding programs because of the relatively long-term nature of cattle genetic selection experiments, the risk that the heritabilities would be relatively small, and/or the risk that there may be unfavourable relationships between NFE and other commercially valuable traits.

This proposed project was funded by the MRC as DAN 75, over the period 1992/93 to 2000/01.

At about the same time, the operational plan for the recently funded Cooperative Research Centre for the Cattle and Beef Industry (CRC I) was being developed. The mission statement for CRC I was: "To assist the beef industry of Australia to meet the meat quality specifications of domestic and export consumers at least cost and maximum profit for all sectors." NFE R&D was not a stand-alone Program in CRC I, but was included as a major component of both the Growth and Nutrition Program and the Breeding and Genetics Program. The broad objectives were firstly, to provide the genetic parameter estimates for feed efficiency of feedlot cattle (heritability and genetic correlations with other important traits), and secondly, to provide knowledge of the biological basis of variation in feed efficiency. CRC I was funded over the period 1993/94 to 1999/00.

The second phase of CRC funding, the Cooperative Research Centre for Cattle and Meat Quality (CRC II) also contained a significant component of NFE work to provide the tools and knowledge to ensure the cost competitiveness of Australian beef in world markets. Project 2.2 was specifically on feed efficiency, and NFE studies were also part of Projects 2.1 and 2.3. Specific objectives were to produce fine scale gene maps for NFE, to develop optimal breeding designs for use by industry, to develop lower cost methods to identify superior NFE animals, and to develop and deliver educational and extension programs to improve the adoption rate of the NFE technology by industry. CRC II was funded over the period 1999/00 to 2005/06, with an overlap year with the last year of CRC I.

In recent years, research has commenced on the relationship between cattle that are net feed efficient and their outputs of greenhouse gas (GHG). Early initiatives aimed to assist in the development of Australian and New Zealand GHG inventory procedures for livestock, and to review potential abatement strategies and R&D directions for livestock GHG emissions. Recent experimental work has focussed on developing improved GHG measurement methodologies to suit grazing industries, evaluating the management of rumen protozoa as a GHG abatement strategy, and evaluating breeding for improved NFE as a GHG abatement strategy.

Specific objectives include:

- Calculating theoretical differences in GHG emissions from cattle divergently selected for NFE;
- Developing and validating new measurement procedures to test the theoretical effect;
- Measuring the effect in 91 cattle selected for NFE;
- Discovering physiological mechanisms that underpin low methane emissions; and
- Calculating the GHG abatement likely to result from expected industry adoption of NFE. If this number is high enough, there is opportunity to claim approximately $5/t funding under the federal Greenhouse Gas Abatement Program (GGAP).

2.3 Inputs to the Cluster

Total inputs to the NFE R,D&E cluster are estimated to be $20.639 million between 1991/92 and 2019/20. This figure is calculated as follows.

2.3.1 NSW Agriculture

Actual project payments from external sources were taken from MRC and CRC documentation. Estimates were made of the full-time equivalent (FTE) staff of different categories involved in the NFE cluster of projects in different years. The 2002 costs for representative FTEs were calculated as salary plus on-costs of 23 per cent, plus management and other overheads. These amounts totalled $136 000 for a scientific research officer, $123 500 for an advisory officer and $108 000 for a technical officer, on an annual basis.

- Between 1990/91 and 1992/93, it is estimated that it took one FTE research officer each year to develop the DAN 75 project and negotiate the contract with MRC (cost=$0.270 million).

- Between 1993/94 and 2000/01, NSW Agriculture was contracted to provide $490,000 each year (in 1992 $) of in-kind contributions to the DAN 75 project (cost=$5.214 million).

- Between 1993/94 and 1999/00, it is estimated that NSW Agriculture contributed 1.1 FTE research officer, 0.25 FTE advisory officer and 1.7 FTE technical officer each year to Beef CRC I NFE activities, plus an additional 0.75 FTE research officer each year from 1997/98 onwards (cost=$2.845 million).

- Between 1999/00 and 2005/06, it is estimated that NSW Agriculture has and will contribute 1.2 FTE research officer, 0.7 FTE advisory officer and 2.1 FTE technical officer each year to Beef CRC II NFE activities, plus an additional 1.4 FTE research officer each year from 1999/00 to 2000/01 (cost=$3.705 million).

- Between 2006/07 and 2010/11 (assuming that the proposed CRC III does not go ahead), it is estimated that NSW Agriculture will contribute 1 FTE research officer, 0.5 FTE advisory officer and 0.5 FTE technical officer each year to NFE follow-up activity to ensure the technology is adopted (cost=$1.225 million).

- Between 2001/02 and 2002/03 it is estimated that NSW Agriculture has contributed 0.75 FTE research officer and 0.5 FTE Technical Officer each year to GHG research, and that this will increase to 0.9 FTE research officer plus 0.5 FTE technical officer each year for the next three years (cost=$0.667 million).

The total cost of these inputs is $14.196 million or $13.925 million on a present value basis using a 4 per cent real discount rate. The majority of these in-kind contributions have been provided by staff currently located at the Armidale Beef Industry Centre. The remaining in-kind contributions have been provided by staff at Trangie Agricultural Research Centre and Glen Innes Agricultural Research and Advisory Station.

2.3.2 External Funding

Where appropriate, actual project payments were taken from MRC/MLA and CRC documentation.

- Between 1993/94 and 2000/01, MRC and one of the breed societies provided $1.890 million to the DAN 75 project (cost=$2.217 million).

- Between 1993/94 and 1999/00, it is estimated that the Commonwealth Government and industry partners contributed $1.310 million to NFE-related research in CRC I. This was calculated as 0.25 of the total value of the Growth and Nutrition Program and the Breeding and Genetics Program (cost=$0.391 million).

- Between 1999/00 and 2005/06, it is estimated that the Commonwealth Government and industry partners have and will contribute $2.360 million to NFE-related activities in Beef CRC II. This was calculated as all of Project 2.2 expenditure, plus 0.25 of the expenditure in Project 2.1 and Project 2.3 (cost=$2.379 milion).

- Between 2001/02 and 2005/06 it is estimated that the Commonwealth Government and industry have and will contribute $0.680 million to NFE-related GHG research. In particular, it is anticipated that $180,000/annum will be available from July 2004 for the foreseeable future, for GHG abatement work (we have limited this to just the three years to 2006/07) (cost=$0.677 million).

- It is estimated that the cattle breed societies have jointly contributed 0.2 FTE of an advisory officer each year to NFE promotion activities from 1996/97 to the present and will continue to do so through until 2019/20. This is estimated to be worth some $0.840 million to NFE-related advisory activities (cost=$0.675 million).

The total cost of these inputs to the NFE cluster from external sources is $5.664 million or $6.714 million on a present value basis using a 4 per cent real discount rate.

2.3.3 Total

The total cost of all inputs is $20.639 million on a present value basis using a 4 per cent real discount rate. Of this total, NSW Agriculture is estimated to have contributed some 67.5 per cent, while the cattle industry and the Commonwealth government is estimated to have contributed 32.5 per cent.

Apart from cooperative projects funded under CRC I or II where NSW Agriculture is the core supplier of R,D&E skills and experience, there are no other providers of the outcomes from this cluster.

2.4 Outputs

The NFE cluster has been essentially a research-based set of activities, and much of the output has resulted from analysis of cattle experiments.

First, a large number of scientific outputs have resulted from the investment in the NFE R,D&E research cluster. The NFE trait has been extensively studied within British breeds of cattle and as such is directly applicable to Southern beef production systems (Exton *et al*., 2000). Research is only in the early stages for *Bos indicus* cattle.

For example, the following results have been found:

- Post-weaning tests for NFE on British breed cattle fed a medium-quality ration have demonstrated that genetic variation in residual feed intake exists, and that the trait is moderately heritable (around 0.4) (Archer *et al*., 1998).
- Heritability of the NFE trait is of similar magnitude to the heritability of growth (Arthur *et al*., 2001).
- Selection for superior NFE has resulted in progeny that eat less with no compromise in growth performance, both in bulls and heifers tested post-weaning (Herd *et al*., 1997), and in young steers fed in a feedlot (Richardson *et al*., 1998; Herd *et al*., 2000).
- Heifer weaners selected for NFE also display improved NFE as mature cows (Arthur *et al*., 1999).
- Cows selected for superior NFE are as heavy, have a similar depth of subcutaneous fat over the rib, and similar milk production to low NFE cows, but eat less (Arthur *et al*., 1999).
- Studies on the physiological basis for feed-efficient cattle have shown that many processes contribute to differences in feed efficiency between animals and among these differences in body composition is only a minor driver (Richardson et al, 2004). There remains 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).

In relation to the GHG component of the cluster:

- Theoretical calculations show that selection for improved NFE should be accompanied by a significant reduction in GHG emissions per day and per unit of liveweight gained (Herd *et al*., 2002).
- Methane emissions by 91 steers from the NFE selection lines were measured throughout 2003, whilst NFE was being determined during feedlot finishing. This study clearly indicated that steers eating less feed produced less methane, and that steers that were low methane producers on one occasion were, in most cases, low methane producers subsequently when tested on the same diet (Goopy *et al*., 2003; Goopy and Hegarty, 2004). The correlation between methane production and the breeding value or realised NFE of steers is currently being determined by biometricians. A subset of ‘high’ and ‘low’ methane producing steers were kept for a subsequent study to explore the physiological basis for differing emissions. In the process of conducting these studies, more robust methods of measuring methane production have been developed and are continuing to be refined. These techniques are not to be exclusively used for NFE studies and will be a valuable addition to all future methane studies (Hegarty, 2003; Hegarty and Machmueller, 2003; Hegarty *et al*., 2003a,b; Hegarty *et al.*, 2004a,b).

Second, there have been some outputs relating to on-farm implementation. For example, a test to measure NFE during the 70-day post-weaning period has been validated (Archer *et al*., 1997), an automated feed-intake recorder for use on farm has been produced with commercial partner Ruddweigh International Scale Company, and a standards manual for conduct of NFE tests has been developed in conjunction with the major Australian breed societies.

Third, there have been some outputs directly applicable to industry breeding schemes. For example, an estimated breeding value (EBV) for NFE has been developed, and has been available in the Angus Society since 2001 and in the Hereford Societies since 2004.

An advisory officer has been part funded within this cluster (particularly during CRC I and CRC II) and as such there have been a large number of advisory activities run in conjunction with the advances in the scientific understanding of NFE. This includes field days, short courses, advisory publications, etc. In addition, a major workshop was held on NFE and the results are being published as a special edition of one of the eminent Australian agricultural science journals.

2.5 Outcomes

2.5.1 Economic

The main outcomes of this R,D&E cluster to date have been economic. It is apparent from the scientific outputs that genetic variation in residual feed intake exists, the trait is moderately heritable (around 0.4), and there does not seem to be any major adverse implications for other traits of commercial importance. Thus breeders can select for NFE and growth and meat quality and not have to make any additional trade-offs. This information has been taken up by the Australian stud cattle industry, stud bulls have been measured for NFE, and EBVs have been made available in some breed societies to assist commercial producers introduce NFE-superior genetics into their herds. The adoption process has commenced, although only at very low rates to date.

An on-farm testing facility has been devised so that individual breeders can measure and monitor their herd with respect to NFE. Unfortunately such a facility is costly to purchase and there is a high opportunity cost in allocating breeding stock to intensive feeding trials, and this has been one reason for the relatively low rates of adoption in the stud sector. However, new research is examining a simple blood test as a way of differentiating between NFE efficient and inefficient cattle.

2.5.2 Environmental

If a cattle producer purchases NFE superior genetics, then over time the herd will require less feed to maintain the same herd size and farm income. This would result effectively in a lower stocking rate and may provide some environmental benefits to the farm in terms of better ground cover, greater water-holding capability and less grazing pressure on preferred pasture species. Superior NFE cattle will also produce less manure and urea and more easily cope with drought conditions.

Alternatively, a profit-maximising producer may wish to increase the size of the herd and increase farm income (Alford, Griffith and Cacho, 2003). The pasture base may be no worse off than before the NFE genetics were introduced, but some of the other environmental indicators may be compromised by the higher stocking rate, such as soil compaction.

2.5.3 Social

Social outcomes from the R,D&E in this area of work are very difficult to identify and to quantify. There is minimal change to farming practices when adopting this technology and there is likely even less change to regional incomes or to regional communities.

One potential social impact is that because the technology has been developed in Australia, the cattle industry will not have to rely as much on imported genetics and there may be a more vibrant set of breed societies and industry organisations because of this. This may also result in greater export opportunities. Further, since cattle selected for NFE can cope more readily with dry conditions, management can be more flexible and the beef industry would not be as adversely affected by droughts. This may provide some social benefits during such times. Finally, since NSW Department of Primary Industries staff members are world leaders in this area of work, there is some broader social benefit from knowing that NSW Department of Primary Industries staff are being well trained, are engaged in path-breaking research and are effectively contributing to industry and community outcomes.

On a broad scale, some winners and losers can be identified, as with any R,D&E that has a particular geographic focus. Thus producers in the southern Australian beef industry who adopt the technology will face increased profits, while those producers who do not adopt (and producers in other beef producing countries) will face decreased profits. These producers will suffer the consequences of the expected fall in beef prices that will result from the widespread adoption of the NFE technology, but will not be compensated for by having access to the technology.

2.5.4 Summary

In the above discussion of the outcomes from this R,D&E cluster, a range of industry goods and public goods have been identified. We cannot place quantitative values on all of these public and private outcomes, but nevertheless we need to form some judgment about whether the outcomes from the research cluster are largely industry goods, or largely public goods, or a fairly even mix of the two.

In very broad terms, our view is that the outcomes have been essentially industry goods to date, but that in the future the outcomes will increasingly be public goods emanating from the GHG research and from other environmental outcomes that follow adoption of the NFE technology. Therefore, since the outcomes have been largely industry goods but the R,D&E cluster is still being largely funded from public funds, our view is that over the next few years every endeavour should be made to gain more industry funding for the ongoing industry-good component of the work, and if that fails then the NSW Department of Primary Industries should withdraw resources from that component of this R,D&E cluster as individual projects are completed. The NSW Department of Primary Industries should however maintain funding for the ongoing public-good component of the cluster and if possible seek further public funds to augment the available resources.

3. Defining the 'With' and 'Without' Scenarios

The intent in this section is to define the 'with' and 'without' scenarios that will be subject to the benefit cost analysis. The objective is to identify economic, environmental and social changes associated with the 'with' and 'without' scenarios. This is done qualitatively at first so that there is at least a listing of all impacts. Then those impacts that we are going to quantify are identified. The differences between the value of the estimated impacts from having access to the NFE technology and from not having access to the technology are then the net benefits of adopting the technology (for two recent applications, see Vere, Jones and Griffith, 2003, 2004).

3.1 The 'Without' Technology Scenario

We know that the rate of productivity gain in the "specialist" part of the Australian beef industry has been about 1-1.5 per cent per annum (Knopke, Strappazzon and Mullen, 1995), well below the agricultural sector average. Productivity growth has been particularly low in the southern part of the industry where cross-breeding has been the main engine of gain[3]. However, Farquharson *et al.* (2003) showed that in relation to within-breed selection, there were signs that productivity in the south had improved in the recent past and was continuing to improve at an increasing rate. That analysis was based solely on increases in growth rates, since carcase traits and other traits like NFE were not available in the Breedplan data that were used.

There are three particular characteristics of the NFE technology that suggest that the future productivity paths suggested by Farquharson *et al*. (2003) can be regarded as the "without" technology scenario.

To begin with, NFE seems to be largely independent of other traits. It is moderately heritable and experimental work has shown very little correlation with the expression of any other traits of interest: "To date, the only significant finding is a small link with leanness (cattle with lower net feed intake EBVs being slightly leaner)" (Sundstom and Herd, 2004). Thus the industry can begin to select for NFE while continuing to *maintain* the growth and carcase characteristics of the herd. However, given the correlations among these traits, the industry cannot jointly select for the best NFE, growth and carcase characteristics, so there will be some reduction in the potential rate of gain in growth and carcase characteristics if selection focuses on NFE, or some reduction in the potential rate of gain in NFE if selection focuses on growth and carcase characteristics. This is allowed for below in the way that NFE is incorporated into the herd.

Second, once we have some idea of the variability of the trait in the population and some idea about how improved NFE impacts on an animal's energy demands, the genetic effect of introducing the trait into a commercial herd can be predicted quite accurately. That is, given realistic assumptions, the outcome in terms of the future pattern of NFE superior genetics is predetermined.

Third, most of the research on NFE has been done in Australia and in the NSW Department of Primary Industries in particular. There is little overseas R&D to draw on, so there are no spill-

[3] In contrast, productivity gains in the northern herd have been quite spectacular in the last decade in particular, with the infusion of *Bos Indicus* genes.

ins of technology possible to create productivity gain if this project cluster had not been undertaken. To the contrary, since the EBV for NFE has been researched in Australia and has been available in the Australian cattle industry since 2001 (a world first), it is possible that there may be some spill-outs of the technology to overseas cattle producers.

Thus, the “without-technology” scenario is the path predicted by Farquharson *et al.* (2003) based on growth traits. That is, increases in progeny liveweight of between 10 and 20kg per year depending on breed, and increases in cow liveweight of between 11 and 14kg per year, depending on breed (their Table 9). These increases in growth rates imply reductions in the variable cost of producing a kg of beef of between 1 and 2 cents per year, depending on breed (their Table 10).

3.2 The ‘With’ Technology Scenario

NFE improvement assumptions within a commercial beef herd were derived from Exton *et al.* (2000). It is assumed that using 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 of NFE are divided 70:30 between maintenance and growth (Exton *et al.*, 2000).

Johnston (2002) reports that data from the Trangie divergent selection lines, after five years of selection, showed average selection differentials of -0.32 and +0.39 kg per day per year for the Low and High lines, respectively. With average feed consumption of around 12 kg per day, these feed consumption differentials represent a potential difference of almost 6 per cent in net feed efficiency. Recall, these are group averages. In terms of individual animals, Johnston (2002) also reports that estimated breeding values for NFE in a group of Angus sires ranged from -1.32 kg per day to +1.23 kg per day, a potential difference of over 20 per cent.

Thus, the 4 per cent genetic superiority assumption used in this analysis is deliberately on the conservative side to account for the trade-offs in selecting for NFE or growth, and the possibility that there may be some as yet unknown adverse correlations between NFE and other traits that would reduce the value of the steers and retained heifers.

Based on the assumed parameters, the herd’s increased NFE after a 25 year time period is 6.9 per cent.

4. Benefit Cost Analysis

This project cluster has been funded since 1990, current projects extend at least until 2005/06, and we have assumed that some public sector and private sector funding will continue for many years after that. These costs have been enumerated in section 2.3 above. We can broadly disaggregate costs incurred by NSW Agriculture and external funds. It is more difficult to disaggregate the strictly public and strictly industry components of these costs, since much of the funding has been made available through the Cooperative Research Centre scheme, which necessarily is a mix of Commonwealth, State and industry funds.

The industry has just started to adopt the technology and the benefits are expected to accumulate over a long period of time (as occurs with all cattle genetics technologies). In this section we attempt to estimate the value of those expected benefits. The potential benefits in the farming system are estimated first, and then these are aggregated up to the industry level. On the basis of past research results (see for example Zhao *et al*., 2000), we can disaggregate benefits into those accruing to cattle producers, to meat consumers both domestically and overseas, and to other input suppliers in the cattle marketing chain. There are of course well-known problems with equating benefits to consumers with benefits to taxpayers, so it is difficult to apportion the benefits from the NFE technology to public and private users.

The annual costs and benefits are then discounted by an appropriate real discount rate and compared using a number of assessment criteria. Thus the analysis is both *ex post* (looking back over some 12 years of funding) and *ex ante* (looking forward to another 20 years or so of minor funding and the accumulation of benefits).

4.1 Valuing Benefits in the Farming System

Previous economic evaluations of the NFE technology (Exton *et al*., 2000; Archer and Barwick, 1999) have used gross margin (GM) and cashflow budgeting techniques to evaluate adoption of the NFE technology. However, these techniques do not account for the technology within a whole-farm context. There is an underlying assumption that there are no adjustments made in other enterprises or in the resources available to the farm. This study undertakes evaluation of the NFE technology at the whole-farm level using different versions of a whole-farm linear program specifically constructed to represent a typical mixed beef-sheep farm on the Northern Tablelands of New South Wales. Such an approach allows the cattle enterprise to expand but also allows other enterprises and farm resources to adjust as well.

4.1.1 The Northern Tablelands Whole-Farm Linear Program

The Northern Tablelands linear programming model (NTLP) is derived from the Victorian Department of Primary Industries' whole-farm linear programs for various pastoral regions of Victoria, as well as previous linear programming models for NSW such as that described by Farquharson (1991). 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 (TGM). Calendar months are used as the time unit.

The coefficients for animal feed requirements are based upon the metabolizable energy (ME) 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, some enhancements suggested by SCA (1990), such as an increased maintenance allowance to account for the higher grazing effort under Australian conditions, were also included.

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 Department of Primary Industries officers and reported in NSW Agriculture *Farm Budget Handbooks* (Llewelyn and Davies, 2001; Webster, 1998). However, management targets such as herd or flock reproductive performance, animal growth rates and pasture growth rates, may be altered in the model. 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 production enterprise selling steers at 20 months (moderate growth); and a heavy feeder steer (HFS) production enterprise. While these enterprises are taken directly from the most recent NSW Agriculture *Farm Budget Handbooks*, the prices used to implement the NTLP model are based on average prices over the decade 1992-2002. This was necessary because of the extreme sensitivity of the optimal mix of enterprises to small changes in output prices, a result quite contrary to normal industry practice on the Northern Tablelands.

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 on the NTLP are available in Alford, Griffith and Cacho (2004).

4.1.2 Implementing the NFE Technology

The increase in net feed efficiency in the cow herd and growing stock described in section 3.2 above was implemented in the NTLP by altering the parameters for the efficiency of utilisation of metabolizable energy for animal maintenance and growth, known as k_m and k_g respectively (SCA, 1990), for each year over 25 years.

Table 1. Outline of the structure of the Northern Tablelands linear program (NTLP) 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)**	**Sign**	**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).

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 for particular purposes,
m refers to maintenance,
g refers to liveweight gain,
c refers to the products of conception, and
l refers to lactation (SCA, 1990).

4.1.3 Alternative Versions of the NTLP

Optimal farm plans for the without-NFE case (Base) and the with-NFE case are required to compare the economic outcomes of adopting the NFE technology in this farming system. These plans were generated by conducting experiments with several different versions of the modelling framework. These included a single-year equilibrium whole-farm LP model (NTLP) and a multi-period whole-farm LP model (NTMP) to examine further the investment aspects of the adoption of a genetic technology that 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) assessed 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 not selling heifers that are instead retained to increase the breeding herd. These herd dynamics can be represented within a multi-period version of the LP model.

4.1.4 Maximising Discounted Total Gross Margins Using a Multi-Period LP

The optimal farm plan. The construction of the multi-period version (NTMP) of the NTLP model is described in Alford, Griffith and Cacho (2004). 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.

First, an optimal farm plan was estimated for the base case of unimproved cows (ie, without the NFE technology). The optimal enterprise mix was 1108 Prime Lamb producing ewes, 1732 19-micron Merino wethers and a cow herd of 127 unimproved cows producing young cattle to turn off at 20 months of age (Table 2).

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

Enterprise	Unit	Base	NFE
Prime Lamb	Ewes	1 108	1 108
Merino Wethers	Wethers	1 732	1 487
Unimproved Cow Herd	Breeding cows	127	-
NFE Cow Herd	Breeding cows	-	147
PV (including livestock capital[2])	$	1 408 912	1 429 695
Difference in NPV	$	-	20 783
Difference in NPV/breeding cow/year (NPV/127cows/25 years)			$6.55

[1] Present value of accumulated Total Gross Margins discounted at 4 per cent.
[2] Salvage value assumptions at year 25 regarding livestock asset values of the farm plan for the different classes of livestock include Prime Lamb producing ewes, $55/hd; Merino wethers, $40/hd; unimproved cows, $425/hd; and NFE cows, $475/hd. Capital values used for the cow herd follow those assumed by Exton *et al*. (2000).

Next, a gross margin budget was developed for the NFE cow enterprise and the enterprise was allowed to be selected by the NTMP model. Further, the initial (year 1) enterprise mix was set the same as the base case (1108 Prime Lamb producing ewes, 1732 19-micron Merino wethers and 127 unimproved cows). However, in Year 1, NFE bulls were selected by the NTMP to put over the cow herd. Over the planning horizon the various livestock enterprises adjusted so that by year 25 the optimal farm plan was 1108 Prime Lamb producing ewes, 1487 19-micron Merino wethers and a herd of 147 NFE cows, an increase in cattle of 15.7 per cent (Table 2). This equated to an improvement in the NPV per breeding cow per year over the base herd of $6.55, using a 4 per cent real discount rate[4]. This compares with the calculated NPV per breeding cow per year estimated by Exton *et al.* (2000) of $6.95. In contrast to the 15.7 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.

Shadow prices. There is another aspect to the results that demonstrates the additional benefits of an LP over a gross margin in valuing the impact of a new technology at the farm level. In particular, on the Northern Tablelands, where a significant pasture feed shortage occurs in winter (Ayres *et al*., 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. This is shown through the shadow prices.

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

[4] A similar analysis using a 5 per cent real discount rate (Alford, Griffith and Cacho, 2004) generated a herd of 123 NFE cows and an improvement in the NPV per breeding cow per year over the base herd of $9.59.

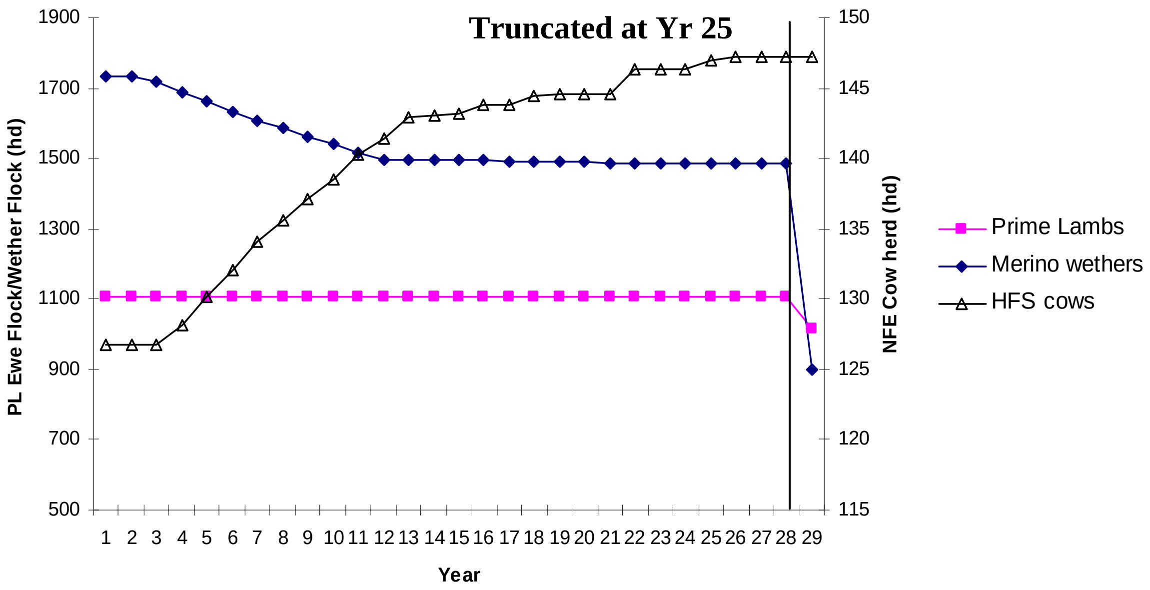
technology. This is also evident in the shadow prices indicated for pastures during the winter months on the representative farm. As can be seen in Table 3, energy from the perennial pasture is a binding constraint in both models, with the shadow prices for perennial pastures in July, for example, with 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 3. Comparison of some binding and slack constraints in the linear program solutions for the with-NFE and without-NFE 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

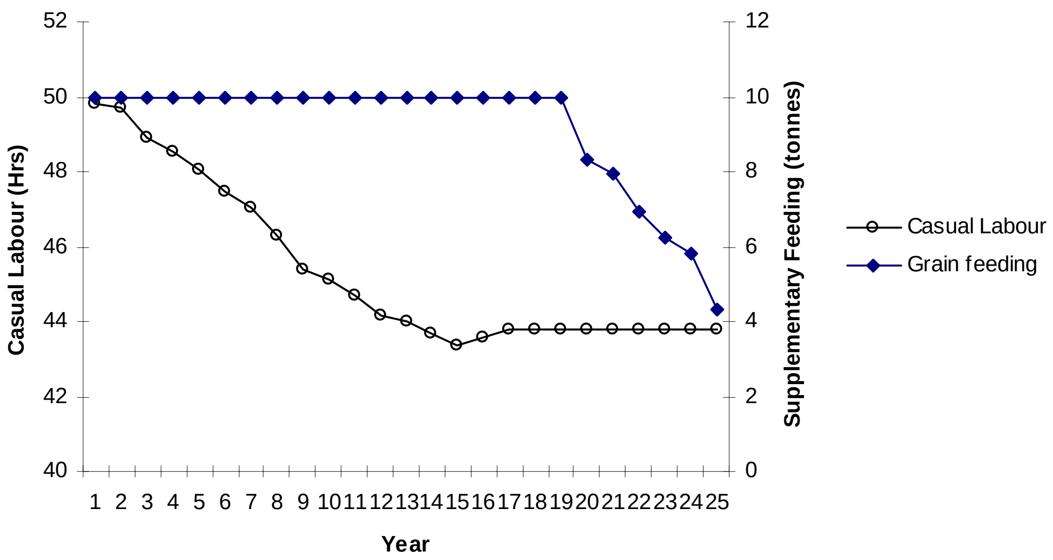
[1] Shadow prices reflect the discount rate used.
[2] Model assumes 50 per cent pasture utilisation, therefore shadow prices can be divided by 50 per cent to obtain indicative price per ME to the animal.

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



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 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



Post-optimality risk analysis. The degree of risk embedded in a technology and farmers' attitudes to risk (especially the degree of 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). However, 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. Pannell, Malcolm and Kingwell (2000, p.75) are sceptical and 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 in deterministic models has been to use @Risk™ (Palisade Corporation, 2001) to incorporate distributions for key variables into the budgets derived from the optimal farm plans, after the optimal farm plans have been selected (see for example, Farquharson 1991). In this section we present a preliminary post-optimality risk analysis based on price probability distributions. We do this experiment because the shapes of the distribution of wool and beef prices are a bit different which means that by increasing the proportion of the farm under beef we forego the opportunity to cash in on the rare occasions when wool prices are very high. We are also interested in uncertainty about the underlying production parameters, but that is more difficult to model in this post-optimality framework.

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 4) and simulations undertaken on the optimal plans for both the without-NFE 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 5) 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.

Table 4. 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 5. 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, 2001)

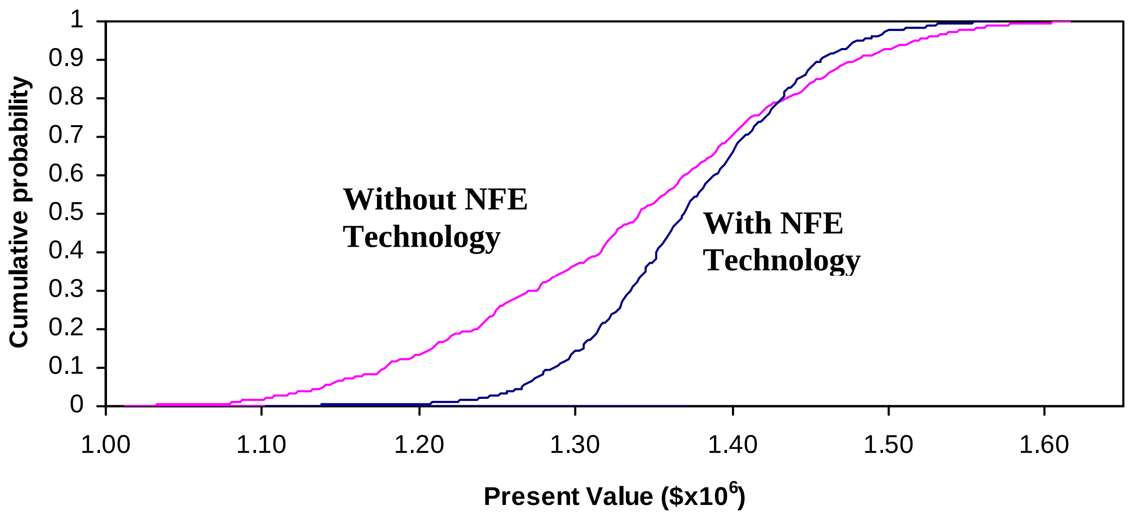
An examination of the simulation results summary (Table 6) and the resulting cumulative distribution functions (Figure 3) suggests that the without-technology plan has a lower average total gross margin, a lower minimum total gross margin and a more variable total gross margin. The with-NFE farm plan lies to the right of the without plan for most of the area, indicating that there is an approximately 75 per cent probability that farm income would be higher for the with-technology case, given the uncertainty in output prices assumed. Therefore, the optimal farm plan incorporating the NFE does not increase income risk from output price variability (although the possibility of high incomes from high wool prices is decreased by adopting NFE). 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.

Comparing the with- and without-technology discounted total gross margins at the means shows a difference of $20,745, or a benefit in favour of the NFE technology of $6.53 per breeding cow per year over the base herd. This is remarkably similar to the $6.55 value derived from the deterministic analysis, and reassures us that we have not made any major errors in using the deterministic solution in our aggregation calculations.

Table 6. Summary results of @Risk simulation

	Without-technology	**With-NFE technology**
Distribution measure	$	$
Mean	1 314 334	1 335 079
Minimum	1 012 921	1 102 090
Maximum	1 615 540	1 567 700
Standard deviation	174 835	135 106

Figure 3. Comparison of the cumulative distribution functions for without- and with-NFE optimal farm plans based upon the sum of discounted total gross margins and present value of livestock



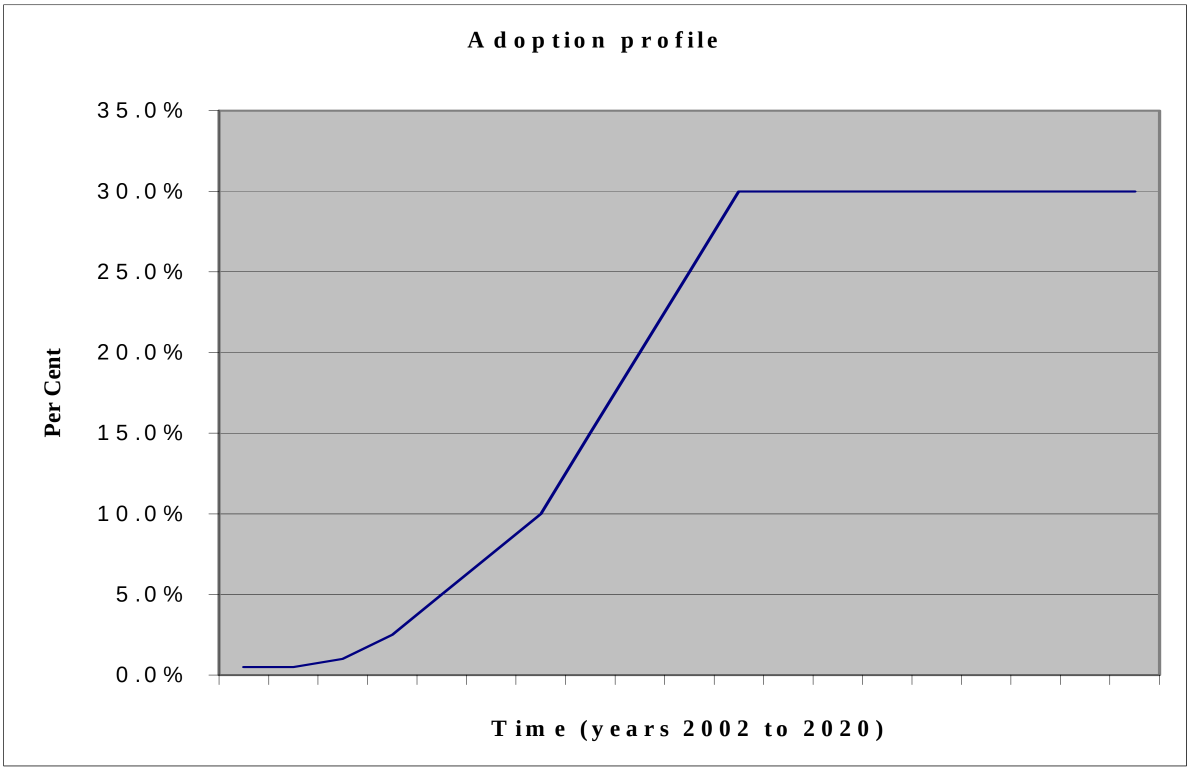
4.2 Aggregation Over the Target Market

To generate an estimated aggregate annual benefit of the NFE technology for the "cow-calf" component of the industry, the chosen value for the on-farm benefit of the NFE technology ($6.55 per breeding cow per year) was multiplied by the number of breeding cows in the southern Australian beef herd, and then by the assumed adoption rate.

From ABARE data, the number of breeding cows in southern Australia has ranged from 5.366 million in 1992 up to 6.102 million in 1997 and back to 5.500 million in 2002. A cow herd of 5.500 million for southern Australia was assumed for the period 2003-2020. The number of breeding cows in NSW has ranged from 2.915 million in 1992 up to 3.243 million in 1994 and back to 2.800 million in 2002. A cow herd of 2.800 million for NSW was assumed for the period 2003-2020.

As described above, adoption of the NFE technology has already commenced with the release of EBVs by the Angus and Hereford breed societies, but it is still at very low levels. The assumed rate and extent of adoption of the NFE technology over the period 2002 to 2020 is shown in Figure 4.

Figure 4. NFE adoption in commercial herds over time (% of herds)



Adoption is assumed to begin very slowly, from a rate of 0.5 per cent of the southern herd in 2002 to 5.0 per cent in 2006 and then more rapidly to the maximum level of 30 per cent in 2012 This level is assumed to be maintained until the end of the period of analysis in 2020.

Annual benefits rise from just $0.180 million in 2002 to the maximum level of $10.808 million in 2012 and thereafter to 2020.

The sum of all these (already discounted) annual benefits to the southern Australia cow-calf sector is $128.609 million. The equivalent benefits to the NSW cow-calf sector are estimated to be $64.305 million.

Following the analysis in Exton *et al*. (2000), some additional benefits of the NFE technology will accrue as saved feed costs in feedlots. Using a budgeting model of a feedlot, a present value saving of $4.34 per breeding cow per year was estimated. To generate an estimated annual benefit of the NFE technology for the "feedlot" component of the industry, the per cow value was multiplied by the estimated number of breeding cows in the southern Australian beef herd that produce export steers (based on MLA and ALFA data on feedlot throughput), and then by the same assumed adoption rate as shown in Figure 4.

Annual benefits rise from just $0.041 million in 2002 to the maximum level of $2.474 million in 2012 and thereafter to 2020. The sum of all these annual benefits to the southern Australia feedlot sector is $29.438 million. The equivalent benefits to the NSW feedlot sector are estimated to be $14.719 million.

The sum of these two sources of aggregate benefit is $158.047 for the whole southern industry and $79.024 for NSW. The aggregate benefit to the national industry will be greater as the NFE technology becomes available for Northern breeds.

The other point to note is that while these benefits accrue to cattle producers and feedlots initially, eventually they are distributed across all sectors of the industry as prices and quantities adjust at different levels of the market. According to the types of results reported by Zhao *et al.* (2000), cattle producers retain about one-third of the total benefits and domestic consumers receive about half of the total benefits.

4.3 Benefit Cost Results

We now have estimates of the value of the R,D&E resources that have been invested in the NFE cluster of projects and estimates of some of the benefits from the adoption of the technologies that have been generated from the investment. Both the cost and benefit estimates are in present value terms and are able to be directly compared.

For the whole Southern Australian cattle industry, the total estimated benefit is $158.0 million and the total estimated cost from all RD&E is $20.6 million. This results in a NPV of $137.4 million, an IRR of 13 per cent and a BCR of 7.7:1.

For the NSW cattle industry, the total estimated benefit is $79.0 million and the total estimated cost by NSW Agriculture is $13.9 million. This results in a NPV of $65.1 million, an IRR of 9 per cent, and a BCR of 5.6:1.

4.4 Comparison to Other Estimates of the Returns from NFE R&D

Exton *et al.* (2000) used gross margin and cashflow budgets to estimate the benefits from improvement in NFE for the commercial beef herd. Their model allowed for an increase of 10 per cent in breeding cow numbers, and they calculated a NPV per breeding cow per year of $6.95, quite close to the value of $6.55 calculated in the present study.

Wimalasuriya, Hamilton and Goldsworthy (2002) undertook a study that aimed to estimate the potential economic impact of achieving productivity gains in a number of research areas in Victorian beef and lamb production systems. They also aimed to estimate the return on investment delivered by three of DPI's existing programs in the beef and lamb industry. NFE in beef cattle was one of the existing projects examined. A number of assumptions about adoption patterns and rates were made, similar in form to those described above in section 4.2. A present value of $17.6 million in benefits to Victoria was estimated to be generated by a present value of $2.2 million in costs (Wimalasuriya *et al*. 2002, p.17). This resulted in a NPV of the project of some $15.4 million and a BCR of 8.0:1, quite close to the summary values estimated in the present study.

5. Conclusions

This report presents the results of one of a suite of five evaluations conducted in 2003 by NSW Agriculture into significant areas of research and extension investment. The particular area of investment examined here is NFE in beef cattle. Feeding cattle is a major cost of beef production. In southern Australian pasture-based systems, around 60 per cent of the variable costs of production are related to feed cost. Supplementary feeding with hay, grain and silage adds further to the cost of feeding cattle, and the cost of feed is around 70 per cent of the variable cost of operating a feedlot.

NFE refers to the efficiency of feed utilisation assessed after accounting for the requirements for growth and maintenance of body tissue. Genetic selection for improved feed efficiency aims to reduce feed-related costs and thereby improve profitability.

NSW Agriculture has been involved in a number of research projects related to NFE since the early 1990s. Total inputs to this research, development and extension (R,D&E) cluster of projects relating to NFE were estimated to be $20.6 million between 1991/92 and 2019/20, on a present value basis using a 4 per cent real discount rate. The total cost of NSW Agriculture inputs was estimated as $13.9 million, on a similar basis. NSW Agriculture contributed 67.5 per cent or more than two-thirds.

The economic benefits of the NFE technology at the farm level were evaluated using a multi-period whole-farm linear program representing a typical mixed beef-sheep farm on the Northern Tablelands of New South Wales. Gross margin budgets were developed for the NFE cow enterprise, for the cow enterprise producing heavy feeder steers (HFS) it would be expected to replace, and for a number of other cattle and sheep enterprises typical of the region. The optimal combination of enterprises was selected when the NFE enterprise was, and was not, available, over a 25-year planning horizon. The net effect of the availability of the NFE enterprise was an improvement in the NPV per breeding cow per year over the base herd of $6.55, evaluated at a discount rate of 4 per cent. This per cow benefit was multiplied by the number of breeding cows in the southern beef herd and by the assumed adoption rate (0.5 per cent in 2003 up to 30 per cent in 2012). An aggregate value of $128.6 million for the cow-calf component of the southern herd was estimated, including $64.3 million for NSW producers.

Next, an estimate was made of the savings in feed costs in a feedlot in southern Australia due to the introduction of NFE cattle. This worked out to be $4.34 per breeding cow per year on a present value basis. This value was multiplied by the proportion of breeding cows in the southern beef herd that generate progeny for feedlots, and then by the same assumed industry adoption rate, to produce an aggregate value of $29.4 million for the southern herd. $14.7 million of this accrued to NSW producers.

Overall, total estimated benefits from the adoption of the NFE technology were calculated to be $158.0 million over the period 2003-2020, discounted at 4 per cent. The share accruing to NSW was $79.0 million.

Comparing the benefits to all recipients relative to the costs incurred by all R,D&E suppliers resulted in a NPV of $137.4 million, an IRR of 13 per cent and a BCR of 7.7:1. Comparing the benefits to NSW producers relative to the costs incurred by NSW Agriculture resulted in a

NPV of $65.1 million, an IRR of 9 per cent and a BCR of 5.6:1. These BCRs are quite similar to values estimated in the context of the Victorian beef industry.

As noted in Mullen (2004), there still seems to be much to learn about how to properly consider environmental and social impacts in analyses of investments in R,D&E activities. One of the difficulties is that economic, environmental and social impacts are not uniquely defined and hence the way of classifying impacts is not unique and the risk of double counting is high. In the approach used here and in the companion evaluations, measures of industry economic performance reflect at least some of the 'on-farm' and industry environmental and social impacts of new technology. However social and environmental 'spillover' impacts on the community are not reflected in industry measures of economic performance.

With regard to *environmental impacts*, the NFE technology has some quite positive potential outcomes. If a cattle producer purchases NFE superior genetics, then over time the herd will require less feed to maintain the same herd size and farm income. This may result in a lower stocking rate and may provide some environmental benefits to the farm in terms of better ground cover, greater water holding capability and less grazing pressure on preferred pasture species. Superior NFE cattle will also produce less manure and urea and will more easily cope with drought conditions. More promising though is the potential reduction in greenhouse gas emissions that seem to result from feed efficient cattle. Selecting for feed efficiency is expected to reduce GHG.

Some important dimensions of *social impacts* are how the benefits of technology are shared between different types of producers and the contribution of new technology to the social capital of communities. We have not attempted here to examine the distribution of benefits between different types of producers and/or different regions (however, we are able to draw on previous work by Zhao *et al.* (2000) and in related papers to note the distribution of total industry benefits from new technology between different sectors of the Australian beef industry).

In addition to the impact on rural communities through economic activity, the number of people living and working on farms, and their skills or human capital, are important to the strength of community service and cultural organizations, referred to collectively as social capital. The social capital of communities is likely to be related to their size which at least in the past has likely been linked with the prosperity of agriculture. Hence, there is concern about the impact of new technology or changes in natural resource policy on the size of rural communities and their social capital.

In general, the impact of technology in agriculture has seen a steady transfer of resources, particularly jobs, to other often non-rural sectors of the economy. This is the story to date of economic development in developed countries. Australian agriculture has a strong export orientation dependent on world prices and hence unless productivity growth in Australian agriculture from new technologies matches that in its competitors, it will become uncompetitive on world markets and the rate of transfer of resources out of Australian agriculture is likely to be faster than otherwise. The relative size of agriculture in the Australian economy is little different to that in other countries, and rates of productivity growth seem similar suggesting that the net effect may have been small. It is also worth pointing out that over the past decade the rate of productivity growth has exceeded the rate of decline in the terms of trade, hence reducing adjustment pressures.

Stayner and Reeve (1990) have noted that there has been a ‘decoupling’ of agriculture and the economic activity of rural communities such that the prosperity of agriculture is less important to the prosperity of rural communities than formerly, although the impact on communities is not uniform. Little is known quantitatively about these types of relationships between rural communities and the agricultural sector. It is unclear what ‘indicators of social capital’ we should be monitoring and what are the empirical relationships between a new farm technology and these ‘indicators’ (valuing environmental impacts faces similar problems). In this evaluation we have settled for a subjective judgment as to whether there were aspects of the technology that were likely to lead to greater community impacts than would be expected of agricultural technologies in general. Again it is important to identify the appropriate ‘with’ and ‘without technology’ scenario.

Thus, social outcomes from the R,D&E in this area of work are difficult to identify. Because the technology has been developed in Australia, the industry will not have to rely on imported genetics and there may be a more vibrant set of breed societies and industry organisations because of this.

Overall, the NFE R,D&E cluster of projects has been an appropriate and profitable area in which NSW Agriculture has invested. Economic benefits have been high, there are potentially quite significant environmental outcomes, and there are no adverse social impacts.

However, while there may have been good reasons for the mostly public funding in the early years of the research, the current mix of funding is perhaps too heavily weighted towards public funds. Those components of the NFE R,D&E cluster that generate essentially private benefits to the cattle industry and cattle producers should be increasingly funded by those groups. The GHG and other environmental components of the work should however be mainly funded by the public sector as the majority of benefits will accrue to society at large.

In terms of project outcomes, there are a number of developments in train that may suggest that the benefits of the NFE technology are quite significantly under-estimated in this analysis. First, there are some new scientific results becoming available that suggest that the potential genetic gain from selection for NFE could be much greater than modelled here (see Johnston, 2003). Second, a new blood test for IGF-I has recently been released, and this could dramatically reduce costs and thus enhance adoption rates and levels. Third, the Beef CRC is currently negotiating a renewal proposal that could provide new funding sources and/or a new funding mix to further enhance adoption rates for NFE.

However, there are some technical modelling issues that require attention in the future. These may suggest we have over-estimated the benefits from the adoption of the NFE technology. First, given the size of the southern Australian cattle industry, it is likely that the widespread adoption of the NFE technology (even at the relatively low levels assumed) will lead to greater output and consequently lower prices. We have not accounted for these impacts on prices.

Second, we have not been able to estimate a change in the average variable cost of producing a kg of beef from the multi-enterprise whole farm LP model described above. This is a necessary input into the industry level models mentioned previously (Zhao et al., 2000).

Finally, there are many uncertainties in this analysis, relating to either the characteristics of the NFE technology itself or the way in which it might be implemented into the farming system. A formal sensitivity analysis of these uncertain values is also required.

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Appendix 1: Calculation of the Farm-level Benefit of the NFE Technology Using A Net Worth Optimisation Criterion

In the second series of experiments, the whole-farm model was expanded to include fixed costs and family drawings for the representative farm (Table A1). 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 A1. 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 A1 and Table A2).

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 A1. The optimal farm plans over time with the NFE technology and with overhead, capital and family drawing constraints

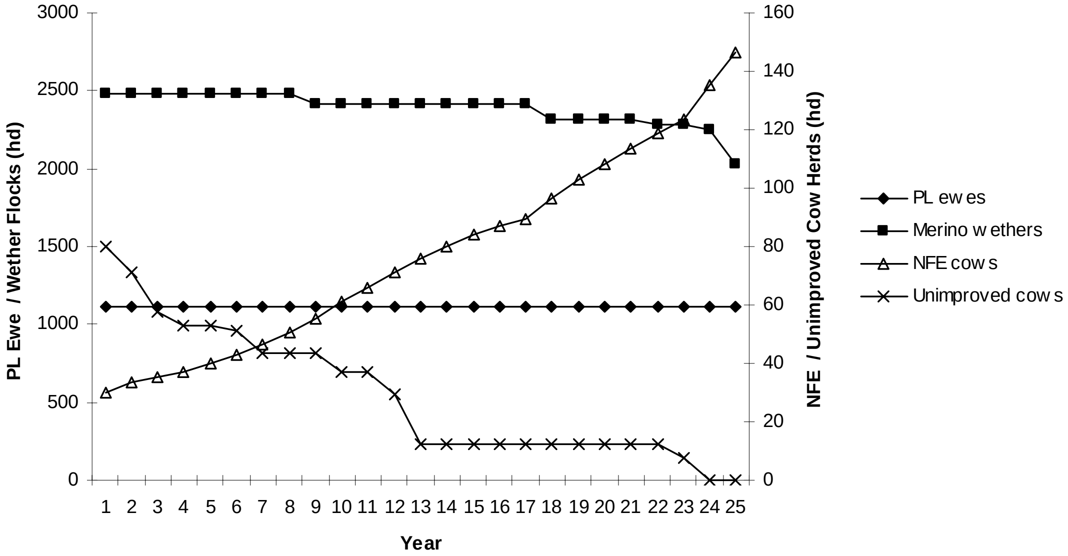

Table A2. Results when optimising net worth

	$
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	299.61
(original herd size) per cow per year	11.98
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 A2 and Figure A1 use terminal values based on a multiple of 1.25.

Results (Table A3) 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 illustrated in Figure A4. 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 A2. The optimal growth in the NFE cow herd for different terminal asset prices

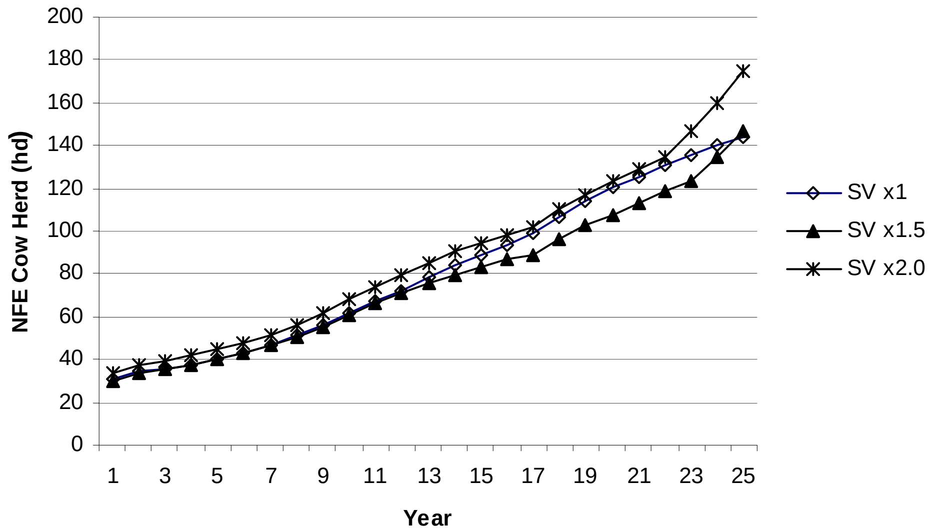

Table A3. The change in farm net worth and optimal plan for different terminal asset prices

	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

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